# G.E.C. Journal

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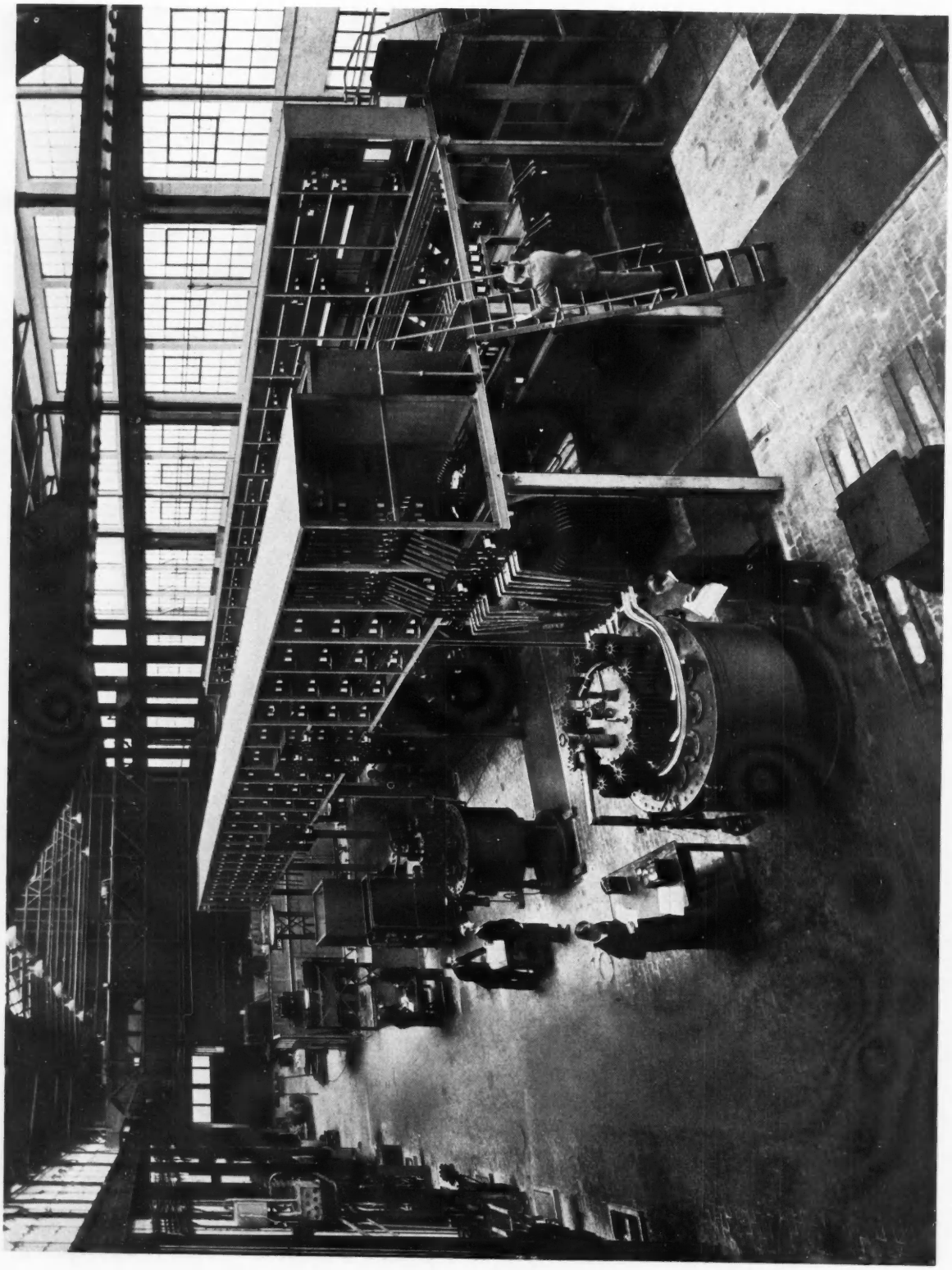


**THE TEST BAY OF THE NEW MERCURY ARC RECTIFIER WORKS.**

**The new Mercury Arc Rectifier Works at Witton, Birmingham, is the first self-contained rectifier works in the world to be erected for the production of both pumpless, air-cooled, steelclad rectifiers and water-cooled rectifiers.**

G.E.C. Journal

VOL. IX. FEBRUARY, 1938 No. 1

# Electrical Progress and Development during 1937.

By H. W. RICHARDSON, B.Sc., M.I.E.E.
Editor of the G.E.C. Journal.

## INTRODUCTORY.

THE record of activities in the electrical industry during the past year is gratifying for two principal reasons; first, it is a record of progressive achievement, and secondly—of even greater importance—it affords evidence that confidence in the future is unabated.

Confidence in the future of industrial conditions finds its expression in the provision of additional facilities for research, in the creation of increased resources for production, and in the opening up of new business channels. Thus the building of laboratories and works, and the establishment of still further branches and agencies by the G.E.C. is evidence of a belief that fundamental trade conditions warrant reasoned optimism.

Of the new works completed in 1937, great importance attaches to the Mercury Arc Rectifier Works at Witton, for it is the first in the world devoted exclusively to the manufacture of the pumpless air-cooled steelclad type of rectifier and water-cooled rectifiers.

The continual increase in research and development work in connection with illumination has rendered necessary additional facilities at Wembley, and new illumination laboratories have been provided in a new wing of the Research Laboratory buildings (fig. 1). Continued advances in regard to telephone cables have led to the building of a new works and laboratory at the Pirelli-General Cable Works at Eastleigh, and already production has been expedited.

Although no epoch making event in electrical science marked 1937, much of value was accomplished; the latest results of research were brought to bear on technical problems, equipment of more efficient and more serviceable types was marketed and new methods of application to manufacturing processes were devised. The more important aspects of these various activities are summarized below, the work of the G.E.C. Research Laboratories forming the subject of the earlier paragraphs.

## TELEVISION.

The regular broadcast of the British Broadcasting Corporation's Television Station at Alexandra Palace, London, began in November, 1936, so that the year under review practically coincides with the first year of high definition television. The decision to use only the 405-line system was made early in the year and simplified the problems of receiver design. The television section of the Research Laboratories in co-operation with the G.E.C. Telephone Works developed three new television receivers which were demonstrated at the Olympia Radio Exhibition in August.

The new Mercury Arc Rectifier Works at Witton, Birmingham, is the first self-contained rectifier works in the world to be erected for the production of both pumpless, air-cooled, steelclad rectifiers and water-cooled rectifiers.

Two of these receivers with picture sizes 10ins. by 8ins. and 13½ins. by 11ins. respectively, have cathode ray tubes mounted vertically, the picture being viewed in a mirror on the underside of the open lid of a table height cabinet. This arrangement permits of the incorporation of all wave broadcast facilities without undue bulk. In these receivers sparkling pictures have been presented, which are many times as bright as those produced by earlier efforts; moreover, a higher standard of quality has been attained. The third model makes a notable advance toward the ideal of popular television, being a "vision only" receiver; it is arranged, however, to operate as a frequency transformer on the sound channel. A pair of leads from the television receiver can be plugged straight into the aerial and earth terminals of any normal medium wave broadcast receiver, so that this will reproduce the sound accompaniment to the picture. With a picture size of 7ins. by 5¾ins. excellent entertainment value is provided.

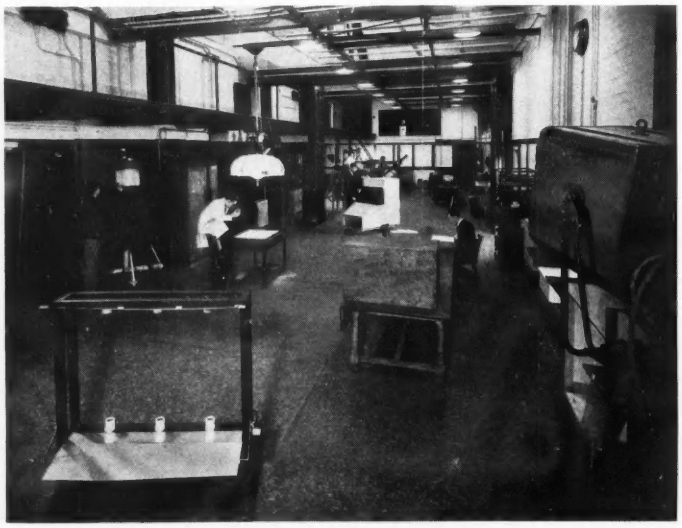


**Fig. 1.—View of the new illumination extensions to the Research Laboratories, Wembley.**

In addition to the immediate development work outlined above, continual investigation has been made into problems of far wider scope. Of great importance, has been the successful completion of the 405-line interlaced transmitter. This is of the disc type for the televising of films; it gives transmission unequalled in quality by any other method so far as is known and among other things assists the study of the problems which arise if the full quality theoretically possible from 405 lines is given by a transmitter.

### CATHODE RAY TUBES.

During 1937 three new cathode ray tubes have been developed for television receivers. The popular 12in. tube has been retained but is entirely re-designed to give a picture of higher brightness and more pleasing colour. The picture brightness now has an intensity of 3 to 4 times that of the old design.

In addition, two other tubes have been developed, the 16in. for the new de luxe receiver giving a picture 13ins. by 10ins. and the 9in. for the new "vision only" G.E.C. adaptor for use as an attachment to existing radio sets.

### TELEPHONE TRANSMISSION.

The rapid development of carrier current methods of communication referred to previously in the *G.E.C. Journal*[1] has progressed to the stage of manufacture and field installation. The subject is dealt with at some length in another article in this issue[2]; therefore here only brief reference is necessary.

The cabling of sections of the London-Cambridge scheme was completed by the Pirelli-General Cable Works. These cables are for operation with "12-channel" carrier systems, and have to meet a new and rigorous performance specification at frequencies up to 60 kilocycles.

Work continues on the design of such multi-pair cables, and also on coaxial type cables both for telephone and television transmission. A carrier system employing equipment produced at the Telephone Works is to be installed on a submarine cable of the concentric type between Nevin in Wales and Howth (near Dublin), using frequencies up to 60 kilocycles per second. This system will be extended later to work up to 90 kilocycles. Every such extension of the frequency range introduces new problems, and to provide for the future in this case a new feed-back amplifier and modulators with exceptionally low distortion and quartz crystal filters have been designed.

### GASFILLED ARRESTORS.

An arrestor, known as type CC.B gasfilled arrestor, suitable for protecting communication circuits, has been introduced. It consists of a cylindrical glass bulb containing a suitable rare gas, into which are sealed three electrodes in the form of parallel plates. The outer electrodes are connected to the lines to be protected, and the centre one to earth.

Under normal conditions the tube is an almost perfect insulator. When, however, due to fault conditions, the potential of either line reaches

1. G.E.C. Journal, Vol. VIII., No. 1, February 1937, p. 6.
2. See page 48.

200-300 volts A.C. above earth, the gasfilling in the arrestor ionises and the tube discharges. The advantage of this type of arrestor is that, once the surge has passed, no attention is required; the device automatically becomes an insulator again. In this way repeated surges of 10 ampere—seconds magnitude can be dissipated without injury to the tube or alteration of its characteristics.

### GASFILLED RELAYS.

A new argon filled relay the G.T.1C has been developed to replace the argon filled relay G.T.1A For voltages below 500 volts it also replaces the mercury filled G.T.1. Being argon filled, the relay has characteristics which are practically independent of operating temperature; this is not the case with mercury filling.

### PHOTOCELLS.

Research work has been directed almost entirely to work on secondary emission cells of the single and multiple stage types. The progress achieved in the development of the former has led to tentative

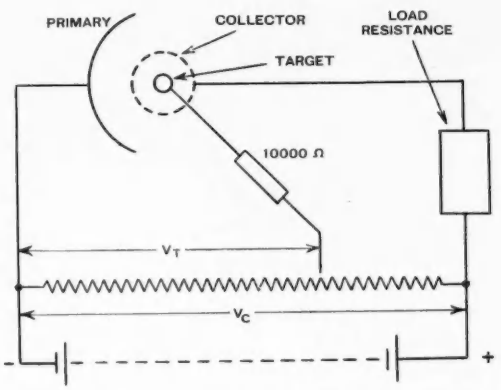



**Fig. 2.—Circuit diagram of CWS.24 secondary emission cell.**

arrangements for a limited sale of secondary emission cells of the cathode-on-wall type, known as the CWS.24. Some progress has also been made with smaller types but these have not yet reached the stage where commercial cells could be considered. With regard to the multiple stage secondary emission cells, experience has been gained with their use in the development of the television transmitter, but, here again, this development has not reached the stage at which it can be exploited commercially.

The CWS.24 secondary emission cell consists of a primary cathode, a target and a collector. When light falls upon the primary cathode, photoelectrons are emitted. These electrons are accelerated by means of a suitable electric field towards the target, where upon impact they release secondary electrons. The ratio of the number of secondary electrons emitted to the number of primary electrons incident upon the target in unit time, is a function of the impact velocity and the target surface. For targets employing the complex caesium cathode, the ratio may be as much as 10 times.

The secondary electrons are attracted towards a collector, and it follows that the collector current

**Fig. 3.—Road brightness readings being taken from a lantern slide projection of a street lighting installation.**

can be several times greater then the original photoelectric current.

In practice, the primary cathode is formed upon the inner wall of a glass bulb, the target on a silver tube in the middle of the bulb and the collector is a wire helix coaxial with and surrounding the target.

The circuit recommended for use with these cells is given at fig. 2. The following values should be noted :—

$V_T$ = 75 per cent. of $V_C$.

Recommended value for $V_C$ = 400V. but may be between 100 and 800 volts.

Potentiometer current — 1 milliamp.

### STREET LIGHTING.

The methods of theoretical and experimental investigation into the appearance and visibility of streets have been used in the study of the effects of mounting height and of location of sources, and these methods have corroborated the design rules which had resulted from observation. A new method for studying experimentally the factors affecting the appearance of streets has been developed, and has already yielded useful results in showing some of the limits of design for both cut-off and non-cut-off distributions. It makes use of the simultaneous projection of two standard representa-

tion lantern slides on to a single screen, fig. 3. It is hoped that this method will yield further useful results in revealing the factors which control the appearance of streets, and will give the data necessary for the interpretation of calculated brightness distributions. Work has been done on vision in streets under sodium, mercury, and tungsten light, and

**Fig. 4.—Street for the demonstration of street lighting at Wembley.**

the conclusion has been reached experimentally and theoretically that no significant difference in seeing is traceable to the type of light source used. This work confirms the results of most other investigators.

Some of the above experiments may give results applicable to a wider field than street lighting, and valuable in other problems of vision and illuminating engineering.

The demonstration road, East Lane, outside the Research Laboratories has been relighted by the Wembley Borough Council, to a plan prepared by the Laboratories. For purposes of demonstration, a new installation has been erected in Second Avenue of the G.E.C. Wembley Estate, fig. 4, in which increased facilities have been provided. Over a length of 1,200 ft., posts have been mounted opposite one another at 150 ft. spacing, with long brackets on which up to four fittings can be fixed and separately switched from a central control hut. Much more complete experiments can be carried out in this installation than were possible at East Lane, though, by agreement with the Council, experiments can still be carried out there if desired.

### AERODROME LIGHTING.

**Course-Indicating Airway Beacons.**

Experiments have been made on scale models on air navigation by various types of course indicating airway beacons. Limitations have been found in existing systems, and a new system has been devised of greater sensitivity, using simpler beacons. A complete scheme of course indications is being worked out, with the object of giving both to pilots and to navigators the maximum amount of information from the ground without the use of any instruments at all on the aircraft.

Continuous study has been made of trough parabolic mirrors for aerodrome floodlights, with the object of improving the quality of the mirrors—which requires to be very high. Much attention has been given also to improvements in the gear for focussing the lamps, and investigations of the suitability of special high pressure mercury vapour sources. This has involved photometry at a range of 500 ft. and a special telephoto camera has been built for studying the "flash" of the mirror at long ranges.

### STEAM TURBINES.

The Research Laboratories have continued their investigations in connection with turbines at the laboratory in Fraser and Chalmers Engineering Works. Four main lines of work have been followed: (1) Investigations on an experimental turbine. (2) Aerodynamic research on blade design. (3) Investigation of blade and wheel vibration. (4) General metallurgical problems.

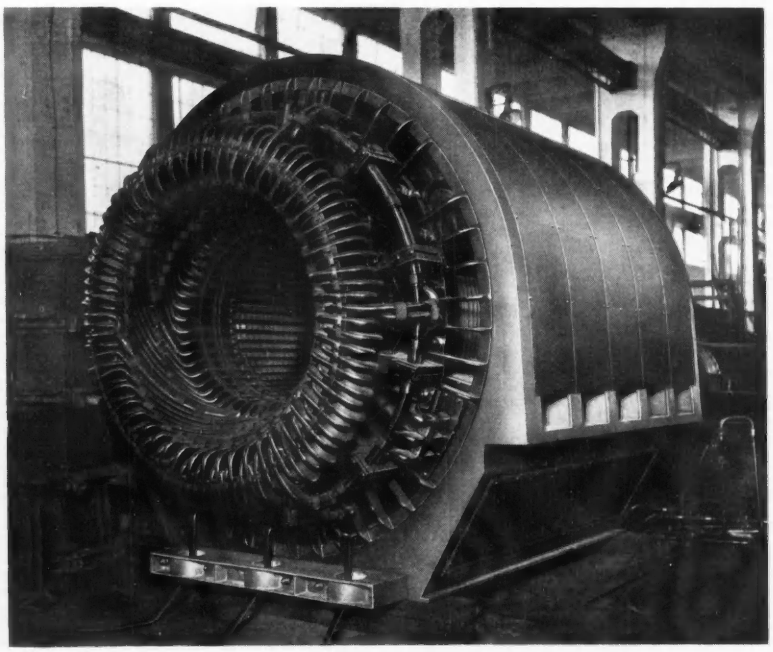


**Fig. 5.—Stator winding of a 31,000 kVA, 20,500 volt turbo-alternator.**

Of these, aerodynamic research on blade design includes the estimation of turbine blade loss from wind tunnel measurements. By extending the tests made on large scale model blades, it is now possible to estimate separately the losses in the blade passages themselves, and the loss due to leakage of steam over the ends of the blade.

Apart from routine vibration testing of turbine wheels, special attention has been given to blade vibrations, and new information has come to light on the interaction of these with vibrations of the disc.

The result of this work on blades is seen in the introduction of new blading in several large turbines now in course of construction.

The new blading ensures uniform distribution of steam over the whole length of the blade during its passage through the stage ; moreover uniform efficiency is maintained. A further advantage is that the tip leakages are reduced by means of special labyrinth seals.

In order to reduce the leaving loss in limit output turbines the area of the last stage has been increased by 14 per cent., the leaving loss for a given steam volume is thus reduced by 23 per cent., or with the same leaving loss the capacity of the turbine is increased by 14 per cent.

The governing of large steam turbines has been further improved. Should a substantial load be suddenly removed from large turbines they are apt to race, particularly if made in two or three casings for high steam pressures, and there is a risk of tripping the emergency governor. To eliminate this risk a solenoid, actuated by the decrease of load, operates the governing relay and closes the throttle valves for a short time interval without waiting for the speed governor which would perform the same function ; the speed governor, however, would operate only as a result of the rise of speed and at a slower rate, so that there would be a greater speed rise. After a short time interval the solenoid is automatically de-energised and the speed governor again takes control of the throttle valves.

In order to prevent large quantities of steam blowing off through the automatic relief valve in case the vacuum falls, an unloading device is incorporated in the governor. This consists of a vacuum cylinder which operates a power piston through an oil relay. When the vacuum falls to a certain limit the power piston begins to move forcing the speed governor into a position corresponding to the reduced lift of the throttle (reduced output). As the vacuum falls gradually, so the steam admission to the turbine is gradually reduced until it is completely shut off when the vacuum has almost completely disappeared.

Research work has also been done on dynamic balancing of large turbine and alternator rotors by electrical means, and the effect of the foundations on the vibrations has been investigated on a small model. A modified form of the apparatus, in which the vibration of the bearings is shown on a cathode ray oscillograph, is being installed for use with alternator rotors at Witton.

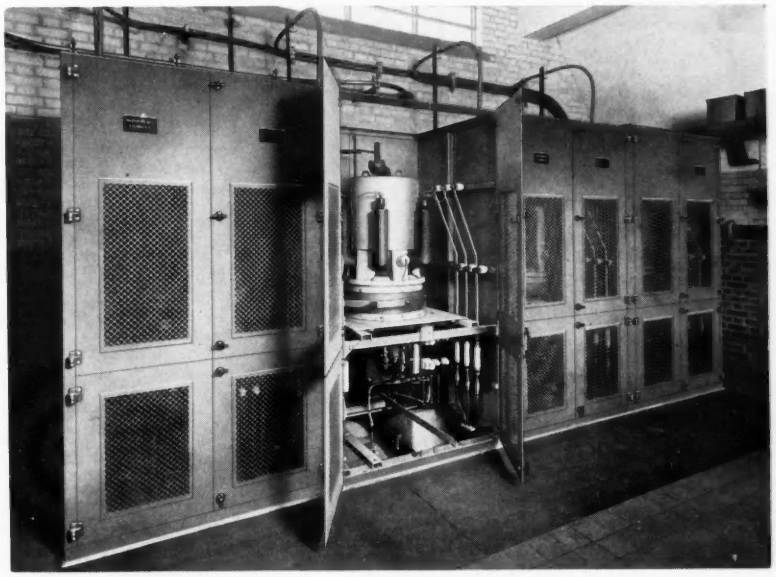


**Fig. 6.—Two 500 kW twin-cylinder pumpless air-cooled steelclad mercury arc rectifiers, 600 volts D.C., installed in the Hammersmith sub-station of London Transport. A total of 26 similar cylinders are now operating on the London Transport system.**

### TURBO PLANT.

A large number of turbo sets have been built both for home and overseas service, and the demand continues. Of those in course of construction reference should be made to a 37,500 kVA 3,000 r.p.m. turbo alternator for the Borough of Woolwich, which is being wound for a stator voltage of 22,000 volts. Other sets of approximately the same size and output are in hand for Stockport, Stepney and Darlington. Geared machines have been ordered by many industrial undertakings, more particularly paper mills and textile mills. In several cases the sets are required for service overseas and constitute repeat orders.

### ELECTRICAL MACHINERY INVESTIGATIONS.

With a view to improving the performance of the larger A.C. and D.C. motors Witton Development Department has carried out a comprehensive

analysis of losses. Better methods of ventilation have been devised, and in the case of A.C. motors starting torques have been increased and starting currents reduced.

Much attention has been given to the analysis and measurement of noises. This has been of great service in the correct appraisement of the noise produced by running machines and has led to the production of more silent running motors.

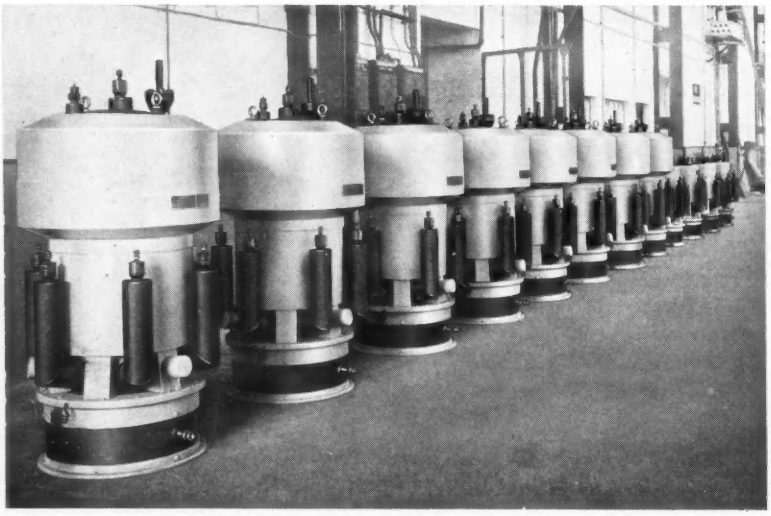


**Fig. 7.—A group of pumpless steelclad mercury arc rectifiers in the new mercury arc rectifier works at Witton. The group includes units for export to Athens, Canton and Melbourne.**

### HIGH FREQUENCY FURNACE SUPPLY.

For providing the supply to a high frequency furnace equipment, a 1,000 cycle single phase alternator has been developed; its output is 400 kVA at 2,000 volts, 1,470 r.p.m. The rotor core is built up of laminations which are slotted to receive the exciting winding. The field coils are inserted in the slots around rotor teeth, thus producing a salient-pole field system with consequent poles. The design has advantages in construction over the homopolar type of alternator, particularly in regard to the suppression of stray fields.

This high frequency alternator is driven by a 650 h.p., 400 volt three phase slipring induction motor of standard frequency.

### MERCURY ARC RECTIFIERS.

The building of the mercury arc rectifier works at Witton, already referred to, is evidence of continued progress. Both the pumpless air-cooled and the water-cooled types have been further developed and improved, and grid control methods have been applied.

The air-cooled rectifier is now manufactured in sizes corresponding to a current range per unit of from 350 to 750 amperes for voltages up to 800. Single units up to 1,000 kW are available for voltages of 1,500 and 3,000. Larger sizes may be anticipated with confidence. A range of 6- and 12-anode water-cooled rectifiers is available with load currents of 1,000 amperes and upwards capable of meeting all the usual commercial requirements up to working pressures of 4,000 volts.

Large numbers of units of both types of rectifier have been and are being built. The demand comes alike from traction, industrial and public supply undertakings situated in many districts in the United Kingdom and also overseas. Some of those which are being exported are destined for Athens, Canton, Melbourne, Perth (Australia), Johannesburg, and Hong Kong (see fig. 7).

### STEELWORKS MOTORS.

Two ranges of motors designed for steelworks use have been developed and are on the market. One of these ranges is a D.C. mill type motor for driving steelworks auxiliaries such as approach and tilting tables, screw-down gear, manipulators, shears, etc. Eleven sizes of this type of motor, ranging in output from 5 h.p. to 150 h.p. have been standardized, each output being designed for a standard speed. The rating is intermittent and the machines

**Fig. 8.—One of the new D.C. steelworks motors shown with the top half of the frame swung open.**

can be either shunt, series or compound wound according to duty.

In order to obtain complete interchangeability the principal dimensions—such as centre-height, shaft extensions and fixing centres—are all in accordance with the standards laid down by the Association of Iron and Steel Electrical Engineers in America.

The motors are made to withstand rough usage, heavy overloads and very rapid acceleration and deceleration. The magnet frames are split, and the top half is hinged so that it can be swung back clear of the armature (fig. 8). The armature, complete with its heavy roller bearings and housings, can then be lifted out. In this way an armature, if necessary, can be replaced with great ease and rapidity. The armatures have similar shaft extensions at each end so that the drive can be from either end according to requirements, or a brake drum can be fitted at one end.

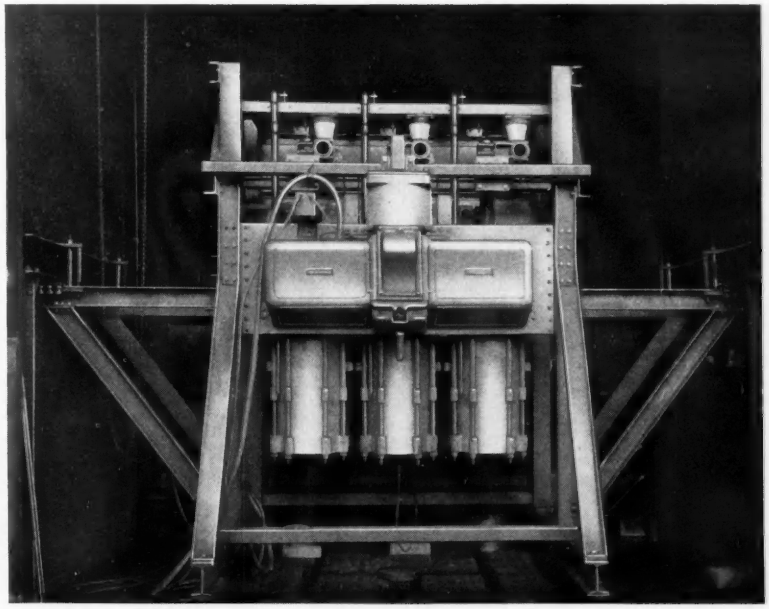


**Fig. 10.—1,000,000 kVA, 6,600 volt oil circuit breaker for Norwich Corporation Electricity Department, erected for test at the Witton High Power Testing Laboratory.**

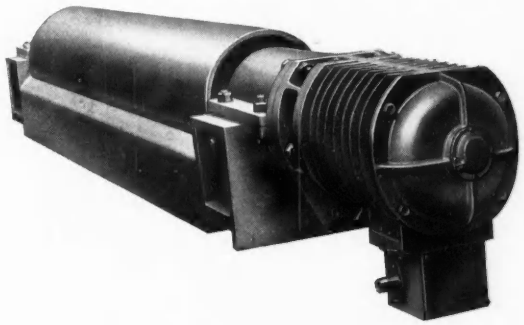


**Fig. 9.—Low frequency live roller motor coupled to a roll of a steelworks live roller table.**

Two important contracts for these mill type motors are in hand, one for 150 machines being for Richard Thomas & Co., Ltd., in connection with the installation of a complete mill at Ebbw Vale mentioned later; the other comprises 100 motors for John Summers & Sons, Ltd. of Shotton, and includes sizes from 7½ h.p. to 150 h.p.

The second type of steelworks motors referred to is an A.C. low frequency roller motor for individual drive, fig. 9, designed to operate at high power factor and high efficiency. The size and cost of the motor is reduced considerably as compared with a 50-cycle machine, and, though a frequency converter is required, the total cost of the low frequency installation compares very favourably with that of a 50-cycle line frequency motor installation.

The employment of a low frequency motor offers many advantages, in particular that the high torque required for the rapid acceleration and retardation demanded by roller table service is obtained without a specially designed high resistance rotor. A total of 123 motors of this type is being manufactured, also for John Summers & Sons, Ltd.

### HEAVY POWER SWITCHGEAR.

The use of condenser bushing busbars for metalclad switchgear has been extended. Previously this type of busbar was employed for voltages of 33 kV and above, both for outdoor and indoor use. Condenser bushings have now been applied to 6·6 and 11 kV gear.

The advantages of condenser bushing busbars are better cooling, reduced fire risk and greater compactness. In addition, extensions are more readily carried out than if compound filled busbars are used.

An example of their use is an 11 kV, 1,000,000 kVA switchboard built for the Clyde Valley Electric Power Co., Ltd. The 2,000 ampere circuit breakers on this board have electrically operated oil immersed busbar selector switches and improved arc control pots. Condenser bushings are used also for the busbars of 11 kV, 500,000 kVA switchboards, under construction for Richard Thomas & Co., Ltd., in connection with the contract referred to above.

Improved arc control pots have been developed for circuit breakers with breaking capacities ranging between 250,000 and 1,500,000 kVA and for system voltages between 6·6 and 132 kV.

In view of the recommendations embodied in the revised British Standard Specification for Oil Circuit Breakers (B.S.S. 116/1937), to the effect that operation at a distance is recommended for oil circuit breakers whose breaking capacity exceeds 10,000 amperes or 150,000 kVA, the range of breakers for which spring closing mechanisms are available has been extended to include those with capacities of 75,000, 100,000, 150,000, 250,000, 350,000 and 500,000 kVA. In the case of the smaller sizes in this range, springs are compressed by means of a lever, while for the larger ratings a hand-operated hydraulic jack is employed.

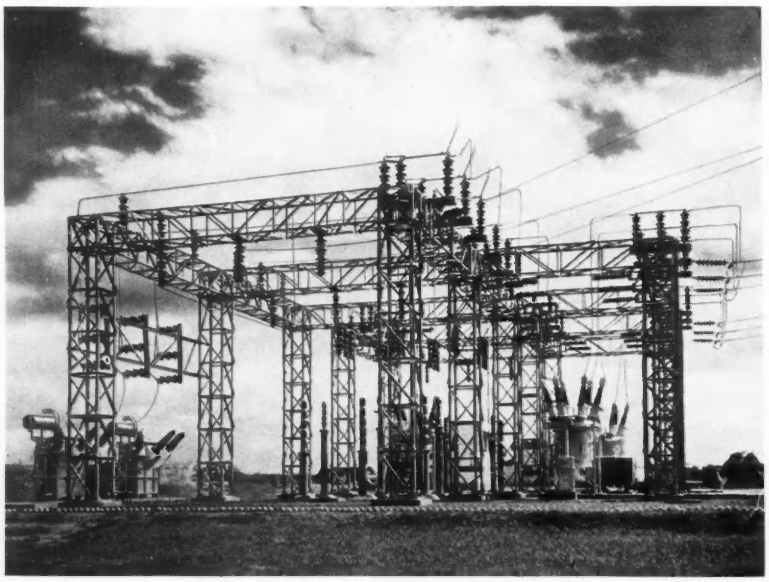


**Fig. 11.—66,000 volt outdoor substation at Singarappet, Government of Madras Mettur Hydro-electric Development, showing air break switching equipment and transformers.**

Among installations of stonework cubicle switchgear, great interest attaches to the equipment for Norwich Corporation Electricity Department. The breaking capacity of the oil circuit breakers employed is 1,000,000 kVA at 6·6 kV. Type tests upon the breaker, the isolating links and the busbar connections were carried out in the High Power Testing Laboratory at Witton (see fig. 10), and in addition to passing successfully the breaking capacity tests, the gear withstood a peak short circuit making current of 266,000 amperes, which, it is believed, is the largest peak current to which a 6·6 kV circuit breaker has ever been subjected under test conditions. In this installation, tubular conductors having specially low resistance to alternating currents are used for the main connections and busbars.

### OUTDOOR SWITCHING EQUIPMENT.

A large quantity of outdoor type switchgear is being supplied for several outdoor substations, which form part of the 33 kV Viziagapatam scheme of the Government of Madras (fig. 11).

An outdoor type of 66 kV circuit breaker has been developed with a breaking capacity of 500,000 kVA, in which the three phases are accommodated in a single tank. A number of these breakers is being constructed for service in South Africa.

Further extensions are being made to the 132 kV outdoor substations on the Central England and South West areas of the Grid.

An auto-fuse isolator (fig. 12) has been introduced, which is suitable for the protection of transformers up to 100 kVA at 11,000 volts. Visible indication is given at ground level that the fuse has blown by the fuse holder dropping down. The fuse is of the expulsion type and a new element can easily be fitted.

A range of outdoor rotary isolating switches has been developed for low voltage distribution systems up to 660 volts, which are suitable for mounting on poles. They are rated at 200 amperes and are available in 2, 3, 4 or 5 pole mountings having phase centres of 9 or 12 inches. Their chief use is for sectionalizing a transmission line, or for controlling a tap-off supply from an overhead line.

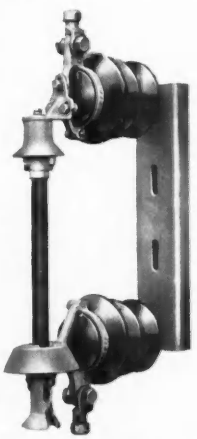


**Fig. 12. Outdoor auto-fuse isolator for the protection of transformers up to 100 kVA at 11,000 volts.**

### INDUSTRIAL SWITCHGEAR.

Industrial oil circuit breakers hitherto have usually been hand operated, but remote electrical control is now available (fig. 14); over 30 units with solenoid operating mechanism have been supplied for controlling motors in a boiler house.

### FLAMEPROOF EQUIPMENT.

The range of component parts for flameproof ironclad switchboards now includes busbar chambers, cable boxes, etc. These components are designed

for use with the standard 15 and 30 ampere double pole flameproof switch fuses, and enable complete unit type switchboards to be constructed having any given number of switch fuses up to the total capacity of the busbars, namely 200 amperes.

A flameproof solenoid, fig. 13, has been introduced and has been awarded a Buxton certificate F.L.P. No. 1006, Group 1. The solenoid is suitable for 440 volts, 3 phase, 50 cycles, and will pull a gross load of 60 lbs. through a 2in. stroke 120 times an hour, or a gross load of 32 lbs. through a 2in. stroke continuously.

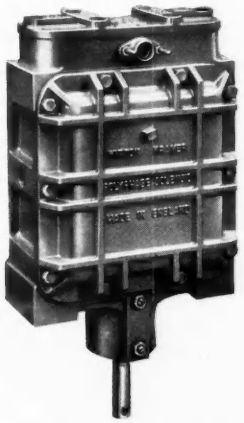


**Fig. 13.—Flameproof three phase solenoid.**

HIGH SPEED CIRCUIT BREAKERS.

Reference has been made previously in the *G.E.C. Journal* to a panel mounted type of high speed circuit breaker, particularly for use on light traction circuits for trolley buses and tramways. There is now a considerable number of these breakers in service ; fig. 15 shows a number mounted on a switchboard in one of the London Transport substations. The operation of the breakers both in service and under severe test room conditions has been most satisfactory. The advantage of installing high speed breakers on traction feeder circuits has again been demonstrated in that track faults are thereby effectively localized. Now that the smaller type of high speed breaker is available the cost of providing this type of protection is considerably reduced.

The type 01 breaker is made in sizes from 400 to 800 amperes, 600 volts, while the type 02 breaker is available up to 1,000 amperes, at 1,500 volts.

RELAYS.

Improvements have been made in the design of existing relays and new relays for specific purposes have been developed. One of the most interesting of the new relays is a supersensitive D.C. moving coil

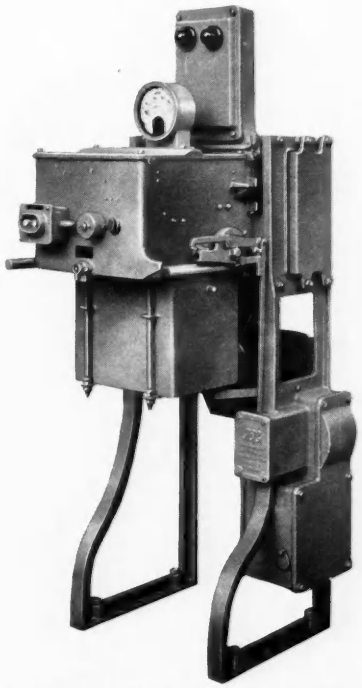


**Fig. 14.—440 volt electrically operated industrial type oil circuit breaker.**

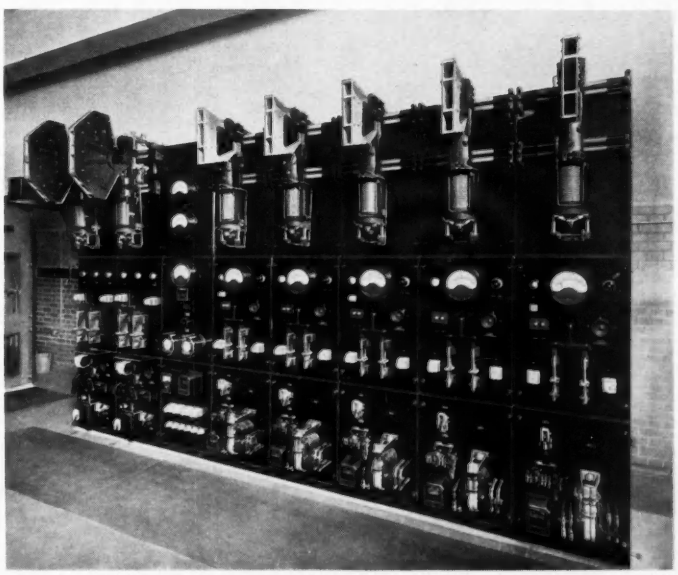


**Fig. 15.—600 volt D.C. control board installed in the Hammersmith substation of the London Transport for the control of the pumpless air-cooled mercury arc rectifiers shown in fig. 6.**

device, fig. 16, for use where only a very small power is available. Robust contacts are operated by this relay with $\frac{1}{2}$ microwatt in the moving coil. It has various applications, one of which is as a master

speed control relay for paper making machinery when the speed of the master alternator set is controlled to limits within $\pm 0{\cdot}25$ per cent.

Hitherto various types of time delay relays have been made for A.C. and D.C. operation. Now a universal design has been evolved. The feeder reclosing relay of this type is shown in fig. 17. It consists of a laminated U-shaped plunger which is

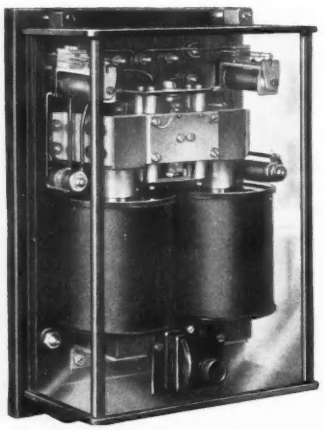


**Fig. 16.—Master speed control relay for paper making machinery.**

attracted into vertical adjacent twin solenoids and comes to rest against a magnetically lagged yoke. The yoke is in the form of a shallow inverted V. The flat tops of the plunger locate themselves to bed down at four points, two per limb, on the yoke.

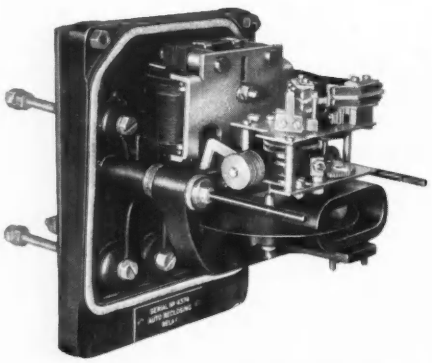


**Fig. 17.—Feeder auto-reclosing relay.**

As a result quiet operation is obtained on A.C. by the provision of an iron to iron contact, while the tendency to stick on residual magnetism on either A.C. or D.C. is negligible.

A standard D.C. busbar relay has been developed both of the polarized and non-polarized types. It is suitable for current up to and including 1,200 amperes continuous ratings. A length of rectangular copper bar has its ends prepared for connection, and its centre carries a glass fronted bakelite box containing the movement. Various contact arrangements are available including a changeover type. A balanced movement enables the relay to be mounted in any position.

## PROTECTION OF MERCURY ARC RECTIFIERS FROM REGENERATIVE BRAKING EFFECTS.

When a traction system is fed from mercury arc rectifier substations, difficulties are sometimes experienced (especially at times of light load), if the rolling stock is fitted with re-generative braking.

It is well known that a normal mercury arc rectifier is not a reversible piece of apparatus, and power cannot be fed from the D.C. to the A.C. system if the power being returned by re-generation exceeds the demand in the section. When these conditions occur there is a rise in the voltage of the D.C. system.

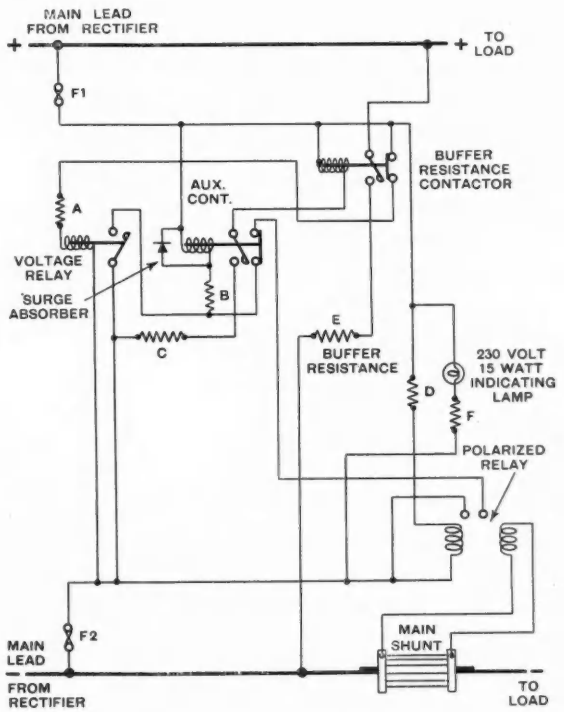



**Fig. 18.—Schematic diagram of connections for re-generative braking for use on D.C. systems supplied by mercury arc rectifiers.**

To deal with the conditions a scheme has been devised which automatically switches a resistance across the D.C. busbars when such an over-voltage occurs, and this absorbs the re-generated power. When re-generation ceases this resistance is automatically switched out again. A schematic diagram of this system is shown at fig. 18. The equipment consists of :—

1. A buffer resistance.
2. A voltage relay.
3. A polarized relay.
4. A buffer resistance contactor.
5. An auxiliary contactor for (4).
6. A main shunt.
7. A pilot lamp, fuses and sundry resistance units for control circuits.

The main shunt is installed in the rectifier output circuit and may be used for ammeter and other instruments as well as for energizing the polarized relay.

The buffer resistance circuit must be fed from the main rectifier leads at a point between the rectifier and the shunt. Should a single train start re-generative braking, the rectifier will cease to supply load to the system and as the re-generated power cannot flow in the reverse direction through the rectifier the system voltage will rise. This rise in voltage will cause the voltage relay to close its contacts. The auxiliary contactor is then energized and closes to energize the buffer resistance contactor, which also closes and connects the buffer resistance across the line. This resistance will absorb the re-generated power and the system voltage will fall to normal. The re-generated current will flow through the main shunt in a reverse direction and thus cause the polarized relay to close its contacts and hold the buffer resistance contactor closed. When re-generation ceases the flow of reverse current through the shunt also ceases and the polarized relay operates to open the buffer resistance contactor.

The buffer resistance must be large enough to absorb the maximum amount of re-generated power which may be expected. Its rating will depend on the duration and frequency of re-generation periods. Usually a rating of 3 minutes every 30 minutes is found sufficient.

### TRANSFORMERS AND TRANSFORMER EQUIPMENTS.

Of transformers which are being built, prominence has to be given to a 45,000 kVA 132/33 kV unit for the Central Board which is to be installed on the North West England area. Other large transformers in course of construction include three equipments for the City of Birmingham Electric Supply Department, one an outdoor unit rated at 20,000 kVA, the second a 20,000 kVA three phase transformer bank, and the third a similar bank rated at 15,000 kVA; the high tension side of all these transformers is 32 kV.

A 15,000 kVA, 33/11 kV transformer is being supplied to Cardiff Corporation Electric Supply Department, while two units of 15,000 kVA, two of 10,000 kVA and two of 7,500 kVA are destined for Palestine.

A 4,000 kVA 6,600/230 volt water-cooled transformer (fig. 19) for use with an electric arc furnace has been exported to Canada. The design of this unit involved several special features. The H.V. winding is provided with six tappings in order to vary the L.T. output voltage over a wide range; in addition the winding can be connected either delta or star to give a total of 12 L.T. voltages. Included in the transformer tank is a large 3-phase iron shrouded reactor for connection in series with the H.V.

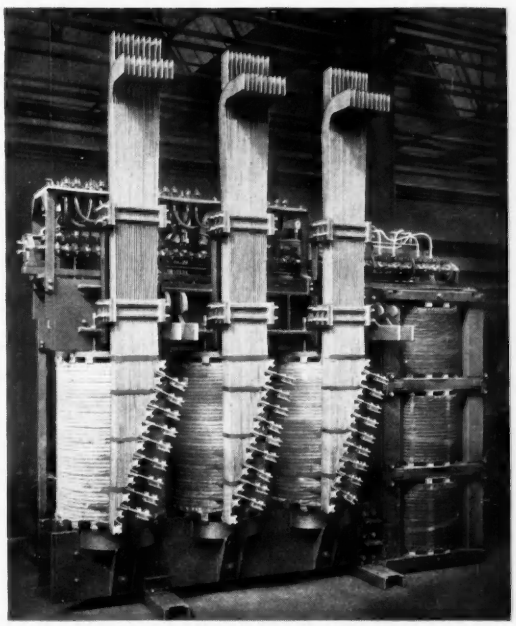


**Fig. 19.—4,000 kVA, 6,600/230 volt water-cooled transformer for use with an electric arc furnace.**

windings. Each phase of this reactor can be tapped to give an additional 30 per cent. reactance with a straight line characteristic up to $2\frac{1}{2}$ times full load.

All the tappings from the transformer and reactor windings are taken to a convenient link board, which is accessible through a man-hole in the tank cover. At the link board four pre-selected sets of tappings can be connected to the contacts of a four-way externally operated switch which is used also for changing the H.V. star-delta connection. Thus the furnace operator, by moving the switch handle at the control board, can make use of any of four L.T. voltages with any pre-selected value of reactance in circuit at each voltage.

The cooling of the oil is effected by means of a large copper tube inside the tank through which cold water circulates. The very low pressure head available made it necessary to arrange that many of the tubes should be in parallel.

### WELDING EQUIPMENT.

Electric welding plant, consisting of both D.C. generators and A.C. transformers, has been in con-

siderable demand, and units from the standard ranges have been supplied for many installations, notably steelworks, tramways, and shipbuilding yards. Typical electric welding operations are shown at figs. 20 and 21.

In connection with the multi-operator type of welding transformer, a current regulator has been developed which results in infinite control over welding conditions.

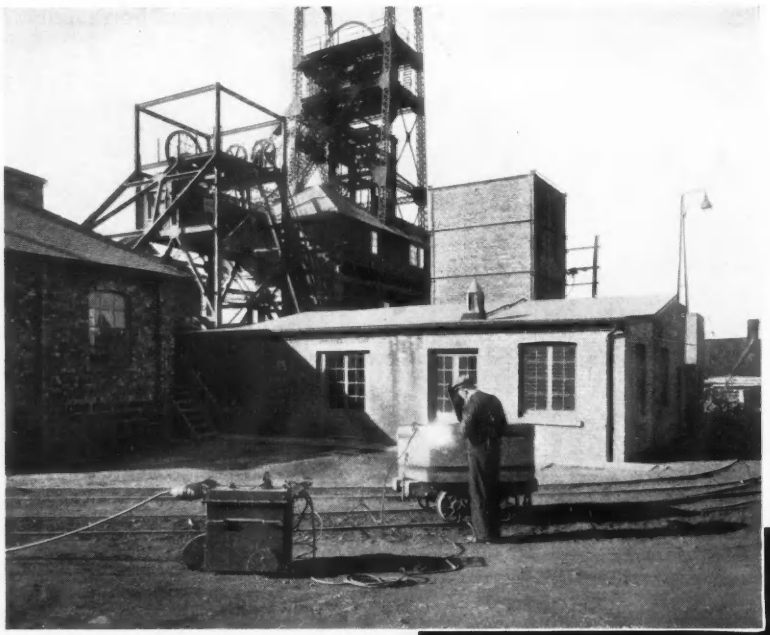


**Fig. 20.—A single operator portable A.C. welding unit employed at the North Skelton Mine of Dorman Long & Co., Ltd., in the repair of damaged coal tubs.**

This unit operates by varying the magnetic reluctance of the core of a carefully proportioned choke coil. The reluctance is varied by means of a handwheel operating a control lead screw. The value of welding current is indicated by a pointer which moves over a graduated scale on the front of the regulator.

### OIL-IMMERSED REACTORS.

Three single phase oil-immersed reactor units which form a three-phase bank have been constructed for the Central Electricity Board for service on the Midland area. The units are connected in a 50,000 kVA 132,000 volt circuit. They have a value of 10 per cent. reactance and are designed to limit kVA capacity between sections of the grid to 500,000 kVA on the circuit.

The reactors are of the iron shrouded pattern, and consist of a heavy disc winding which is supported in the iron shroud. This construction is one which gives great mechanical strength, the shroud performing the dual function of supporting and bracing the winding, besides providing a path for the magnetic flux and thus acting as a shield for the tank.

### INDUSTRIAL ELECTRIFICATION.

Many steelworks schemes were commenced in 1937. Of outstanding interest is the electrically driven mill for hot and cold rolling of strip and tinplate being installed by Richard Thomas & Co., Ltd., at Ebbw Vale. Important sections of the equipment have been entrusted to the G.E.C. The majority of the mechanical plant required for the cold rolling section of the scheme is being manufactured at Fraser & Chalmers Engineering Works; it includes three skin pass mills (comprising 6 housings each of 56 tons), the shearing line, a number of coilers, de-coilers, shears, a tensioning device and other auxiliary apparatus in connection with the manufacture of cold sheet and tinplate. Electrical equipment is being made at Witton for the 3-stand tandem cold strip mill; it consists of three direct current motors each of 1,500 h.p. output, and a 400 h.p. D.C. motor, all four machines being supplied from a 3,500 kW synchronous Ward-Leonard set. Other

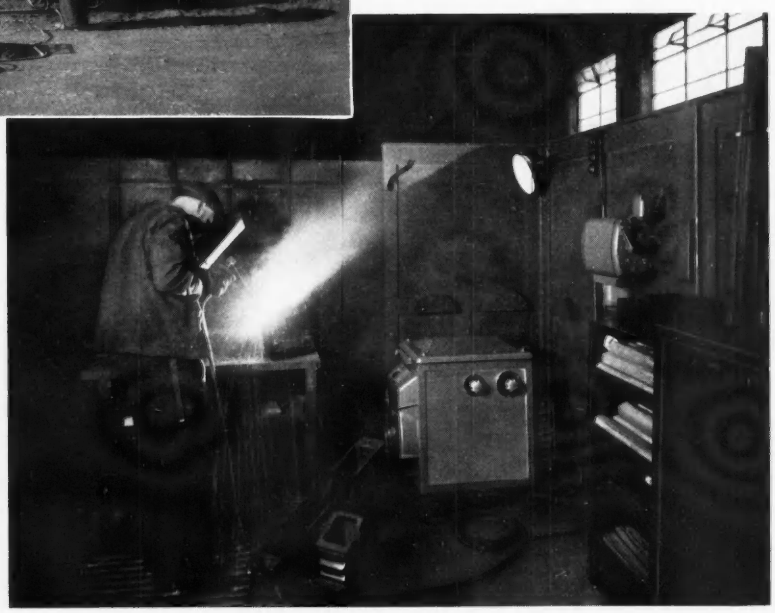


**Fig. 21.—D.C. arc welding in the Queen's Road Depot of the Sheffield Corporation Tramways Department.**

electrical gear being built consists of a number of motors for the individual stands of the hot strip mill, 150 D.C. reversible mill type motors for driving mill auxiliaries, and two metalclad switchboards; one consists of 18 units of 11,000 volt remote electrically controlled gear of 500,000 kVA rupturing capacity which controls the whole of the hot mill; the other comprises 11 units of the same voltage and rupturing capacity, and these control the whole of the cold mill.

A comprehensive steelworks electrification scheme has been completed recently at the Cleveland Works of Dorman Long & Co., Ltd. It is hoped to give a full description of this equipment in an early issue of the *G.E.C. Journal*.

Another steelworks which is being equipped is the Karabuk Steelworks, Turkey. For this installation the principal plant under construction consists of two 12,500 kVA, 3,000 r.p.m. turbo-alternators, three high pressure turbines direct coupled to turbo blowers with a capacity of 30,000 cu. ft. per minute, two 750 kW motor generator sets, switchboards of various types and two 1,000 kVA transformers.

A complete electrification scheme is in hand for a tube works in Jarrow. Among the several large motors is a 720 h.p. slipring induction machine and a 540 h.p. D.C. motor arranged for Ward-Leonard control.

Much work of an interesting character has been undertaken in connection with paper mill electrification. A comprehensive installation has been completed recently for Imperial Paper Mills, Gravesend, Kent. The "Witton" unit sectional drive for paper making machines is employed. It is hoped to publish a full description of the installation in an early issue of this Journal. Another scheme deserving prominence is for the Dartford Paper Mills. This involves the installation of special motors and control gear (fig. 22) and also embodies the "Witton" unit sectional drive. For the new Mersey Works, Warrington, of Thames Board Mills, Ltd., 250 induction motors with aggregate capacity of 3,000 h.p. have been built. Fig. 23 shows a view in this works.

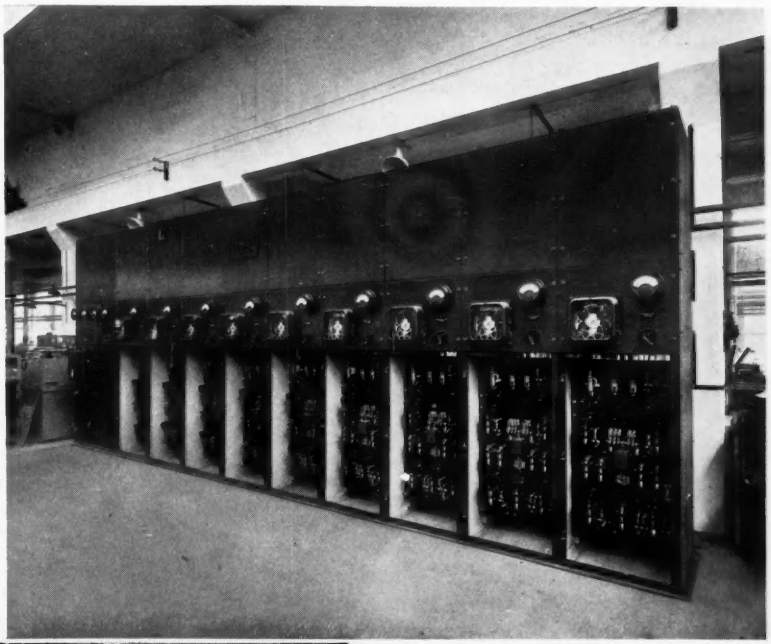


**Fig. 22.—Control switch board for installation in the mills of the Dartford Paper Mill Co., Ltd. View taken in Witton switchgear works during construction.**

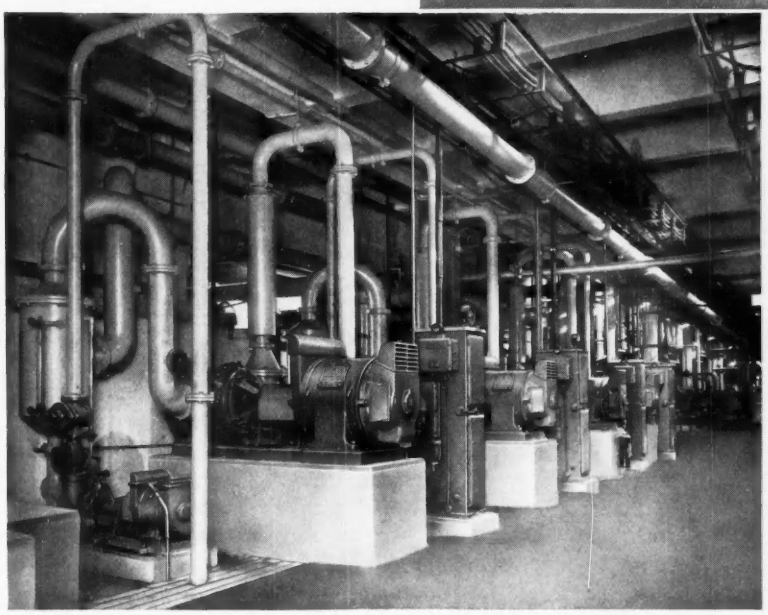


**Fig. 23.—65 h.p., 440 volt pipe ventilated slipring motors driving vacuum pumps at the Mersey Works of Thames Board Mills, Ltd.**

An electrically driven mill for the production of paper pulp from bamboo has been installed in Trinidad. The plant and apparatus includes turbo-alternators, switchboards, motors, motor control gear, cables, lamps, etc. It is hoped to describe also this installation in a

future issue of the *G.E.C. Journal*. A contract equally as comprehensive as that at Trinidad is being undertaken in India for the Star Paper Mills.

A large number of electric winding equipments

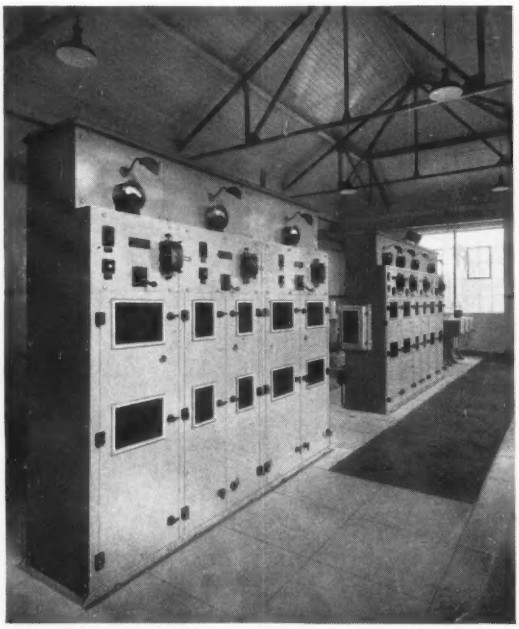


**Fig. 24.—Automatic control boards for regulating the operation of pumps according to the amount of sewage flow at the Sewage Disposal Works, Southampton.**

for mines and collieries have been completed, and many more are in course of manufacture. South Africa continues to place extensive contracts for winders. The majority are D.C. driven and embody Ward-Leonard control.

For A.C. winders a number of electrically operated high voltage air break reversing contactors has been made. They are provided with interlocks to prevent the forward and reverse contactors from being closed at the same time. Four of these contactor groups are for the control of 1,800 h.p. motors.

A particularly interesting scheme is for the conversion of the Randfontein Stubbs Shaft winder from hand control to automatic. The winder is to be operated by push buttons which initiate each wind. After this the control system takes full charge until the cage is decked and the brakes applied at the end of the wind. No further action is necessary on the part of the driver until he starts the next wind. All the usual safety devices are provided, including slow braking in emergency trip-out.

A 2,500 h.p., 6,600 volt synchronous motor driven compressor for the Palmieutkiul Gold Mining Co., Ltd., South Africa, possesses features of great interest. The motor is designed to drive a Fraser and Chalmers air compressor through speed increasing gears, the motor running at a speed of 1,450 r.p.m., and the compressor at 5,250 r.p.m. The compressor has a capacity of 12,000 cu. ft. of free air per minute at a pressure of 90 lbs. per sq. in. The motors run on a 51·5 cycle supply.

The installations illustrated at figs. 24 to 26 are typical of the many industrial electrification schemes which are continually in hand; considerations of space forbid more than passing reference to those schemes.

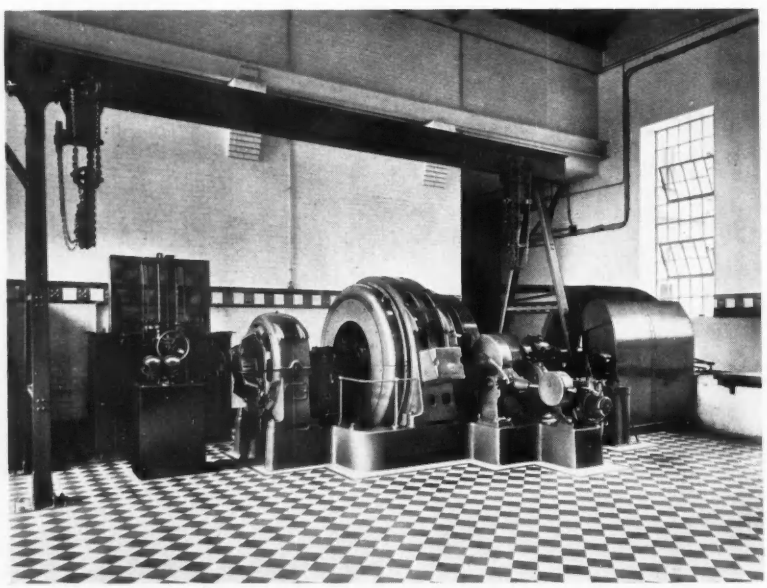


**Fig. 25.—550 h.p., 6,600 volt synchronous induction motor driving main machinery through ropes at the Solent Flour Mills of Joseph Rank Ltd.**

### ELECTRIC TRACTION.

The chief development in electric railway traction during the year has been the production of an entirely new motor of small overall height for London Transport's new high speed tube stock. A total of 812 of these motors is being made which have many special features of design. The output of each motor is 170 h.p. at the one-hour rating and the speed 790 r.p.m. at full field, with a continuous rating of 172 amperes at 575 volts full field. The motor drives a 30in. wheel and the output mentioned is considerably in excess of that hitherto obtained from motors mounted on driving wheels of this size. The small wheel and the overall height of the motor have been necessitated by London Transport's decision to use the whole of the length of

the new trains for passenger accommodation and to do away with the raised platform floors over the motor bogies, which are necessary with the larger sized motors and wheels now used. This innovation is of particular importance so far as tube trains are concerned, for an increasing number of passengers has to be catered for in peak hours, and, because of the extremely high civil engineering costs involved, it would be uneconomic at the present time to increase the platform lengths in order to accommodate longer trains. The new motor has been designed to provide the flattest possible speed tractive-effort curve and to give a low balancing speed in the tube sections. This enables maximum acceleration to be maintained up to full speed, limited only by wheel adhesion. Moreover, the low balancing speed gives a comparatively low speed at which the brakes are applied. Higher balancing speeds are obtained outside the tube sections by field weakening.

Six experimental multi-notch control equipments have been supplied to London Transport Tube Railways. These equipments were designed to enable train units to carry more passengers for the same length of train and to give a higher acceleration and speed. A full description of these equipments appeared in a recent issue of the *G.E.C. Journal*.[4]

Other interesting railway equipments are those for Glasgow Subway which are of the remote control type with full automatic acceleration. For London Transport, the G.E.C. is supplying electrical equipment for six special constructional locomotives which are battery and third-rail operated.

The use of the trolley bus by traction undertakings continues to increase. Important orders for trolley bus equipments have been received from London Transport, South Lancashire Transport Co., Birmingham Corporation, Perth (Australia), Hobart (Tasmania), Copenhagen and Canton. The Canton contract is of a most comprehensive nature and includes 70 complete equipments for single deck trolley buses, together with the whole of the power rectifying plant required for the traction system, switchgear, transformers, feeder pillars, telephone equipment and cables, etc. The power rectifying equipment comprises thirteen 300 kW pumpless air-cooled steelclad rectifiers. Probably this is the largest single order which has ever been placed from overseas for trolley buses.

The equipments made for the South Lancashire Transport Co. have been supplied as a direct result of a sample G.E.C. standard regenerative equipment supplied to this transport authority over a year ago. During this period it has been in constant operation and has given satisfactory service.

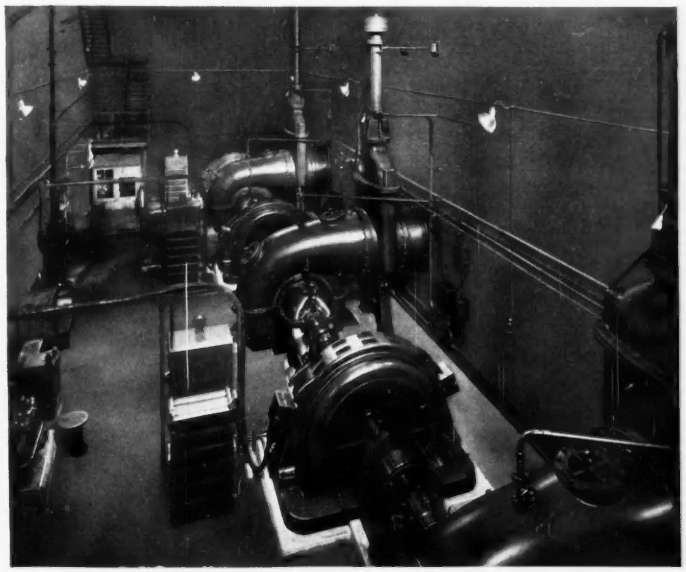


**Fig. 26.—General view of the Dry Dock pumping station at Avonmouth Docks, which contains three centrifugal pumps driven by 650 h.p., 6,600 volt motors.**

MARINE ELECTRIFICATION.

A continuous flow of engineering plant has been passing through Witton works during the year for installation in many new ships under construction. One of the most interesting of these is the Cunard White Star liner *Mauretania*, for which over 100 motors are being supplied for ventilating and air-conditioning equipment. Three 1,000 kW G.E.C.-Fraser & Chalmers turbo-generators are being manufactured for a new vessel being built for Royal Mail Lines, while a large amount of generating plant, switchgear, motors and starters for engine room auxiliaries, compressors, pumps and boiler room fans, have been produced for ships under construction for Houlder Brothers, Ellerman Lines and for the Union Castle Line.

Propulsion equipment for a diesel-electric ferry has formed one of the most important developments of the year and it is hoped to give a full description of this electrification in an early issue of the *G.E.C. Journal*. The main control board is shown in fig. 27.

A considerable amount of heating, lighting and cooking equipment, telephone apparatus, cables, etc., has also been produced during the year for various ships. A good example of this is furnished by the new 23,000 ton P. & O. liner *Stratheden* in which has been installed the lighting fittings for many of the public rooms, a comprehensive telephone service,

4—G.E.C. Journal, Vol. VIII., No. 3, August, 1937.

luminous call system, fire alarms and an extensive electrical galley equipment.

**Fig. 28.—One of the escalators at Earls Court Exhibition building.**

### ELECTRIC LIFTS AND ESCALATORS.

The electric lift and escalator equipment at the new Earls Court Exhibition building—opened during the summer—presents many interesting features. In all, 14 lifts and 6 escalators were supplied by the G.E.C. and its subsidiary, the Express Lift Co., Ltd.

Five high speed lifts are provided for passenger service. Their capacity is commensurate with the needs of the building, four being designed for loads of 20 passengers and one for 40 passengers.

Four of the lifts run at a speed of 450 ft. per minute, and one at 175 ft. per minute. All are fitted with Ward-Leonard control. All landing doors and the car gates are electrically operated, a new operator of novel design being employed which renders the doors and gates absolutely safe in operation. Luminous electrical indicators on the landings and in the cars indicate the position and direction of travel of the latter at all times.

**Fig. 27.—Control board for a diesel-electric ferry.**

There are five goods lifts, designed to raise loads of 3,000 lbs. at a speed of 150 ft. per minute. This is an unusually high speed for lifts of this size, the usual speed being in the region of 50 ft. per minute. These lifts are entirely automatic; by means of a recently developed system of control they level accurately at each landing, in spite of the heavy load and high speed and irrespective of the car being laden or empty.

In the case of the goods lifts all gates are manually operated. Those on the landings afford complete fireproof protection when closed, although they collapse into a very small space when open, so as to provide a maximum opening for loading and unloading.

In order to save time and to prevent damage to goods in unloading from lorries into the lifts, and again from the lifts to the stores, the lift equipment includes three special lorry lifts, so that lorries can be driven into the lifts, taken direct to their respective destinations and subsequently driven out for unloading as required. The lift is thus free to continue in service, and a vast amount of stores can be transported in a very short space of time.

Each of these lorry lifts is capable of raising a load of 20,000 lb. at a speed of 30 ft. per minute. In spite of the very heavy load, the accuracy of levelling is necessarily high in order to deal satisfactorily with wheeled traffic. The cages are 10 ft. wide, 20 to 25 ft. deep and 12 to 15 ft. high and, apart from the hardwood floor, are constructed entirely of steel. They are of exceptionally heavy construction, and weigh approximately from 8½

to 13 tons. The total load is suspended by eight steel wire lifting ropes, the cage and counterweight being fitted with pulleys to give a 2 : 1 roping system, so that the cage is actually suspended by the equivalent of 16 ropes.

The rapid transport of chairs is another necessary feature of such a building as this, and a lift specially designed for this purpose has been installed. It carries loads of chairs of 6,000 lb. at 35 ft. per min., and in view of the bulky nature of the articles to be carried, a large car 9 ft. wide, 12 ft. high and 19 ft. deep is provided. As in the case of the ordinary goods lifts, the lorry lifts and chair lift are fitted with collapsible steel doors on all landings.

Each of the six escalators, fig. 28, has a capacity of 8,000 passengers per hour, and the speed along the incline is 90 ft. per minute, the vertical rise varying from 32 ft. to 37½ ft. Two escalators are installed side by side at the main entrance in Warwick Road, one at each of the two other entrances to the building, and one on each side of the swimming pool.

Special features of design eliminate noise and ensure perfect safety of operation. On each escalator the steps are carried by about 550 rollers which are fitted with grease-sealed double ball bearings mounted in such a way that they rotate continuously, preventing flats from wearing on the periphery and thus causing unpleasant squeaks. In order to prevent a "grinding" noise from hard rollers running on steel tracks that have become dirty, brushes are attached to the step chains; these sweep the entire track formation during the whole time the escalator is running, thus keeping it clear of dirt. A canvas rim is fitted to the rollers to reduce the noise between rollers and track; this type of rim, which is moulded integrally with the roller under high pressure, has been subjected to upwards of four years' heavy continuous duty without any sign of wear. The possibility of a hard "metal-to-metal" noise between the steps when running light has been eliminated by cushioning the step spindles in oil-resisting rubber bushes, which also impart a slight resilience that improves the running under all conditions. Finally, insulation is interposed at all points where there is a possibility of noise being transmitted between components.

The treads are of moulded construction, with the cleats integral with the board giving a closer tooth formation than is obtained with wood; the smallest heel cannot become trapped and an extremely hard-wearing and relatively "non-slip" surface is obtained.

The drive of the escalators is by means of a 46 h.p. motor through worm reduction gearing and roller chain. Each escalator can be run in either direction by means of push buttons.

As examples of the safety devices employed it may be mentioned that should the main driving chain break, current is switched off and the brakes are applied bringing the escalator to rest. A self-wrapping brake whose retarding effort increases with the load, prevents the escalator from beginning to run in the down direction if it has been stopped for any reason. In the event of breakage of either of the chains carrying the steps, current is switched off immediately, and the sprockets are prevented from rotating by means of a powerful brake. Speed governers are fitted to limit the speed of the escalator to a safe maximum figure.

A full description of the Fraser & Chalmers hydraulic lift equipment for the adjustable floors of the swimming pool at Earls Court was published in the previous issue of the *G.E.C. Journal*.[3]

### MATERIALS HANDLING PLANT.

A large number of materials handling plants has been installed in industrial undertakings throughout the world. An ore bedding plant for a new steelworks in England calls for special mention. It is designed to provide as nearly as possible a uniform stock pile of ore of uniform quality, because uniformity tends to increase blast furnace efficiency.

3—G.E.C. Journal, Vol. VIII., No. 4, November, 1937, p. 249.

**Fig. 29.—Self-weighing coal handling plant at Lunghai on the Yangtze River, China.**

Ore from any one source varies in quality and the function of the plant is to spread in shallow layers the ore as received in trucks so that a uniform mass may be stored. Reclaiming of the ore is by means of a Robins Messitor reclaimer which scrapes the ore from the pile in such a way that it retains the uniformity in which it is put into stock. This plant is the first of its kind used in England, and it is believed to be the first in the world for the particular application described.

**Fig. 30.—Witton-Kramer hot ingot lifting magnet.**

### HOT INGOT LIFTING MAGNET.

A Witton-Kramer hot ingot lifting magnet (fig. 30) has been made for the Cleveland works of Dorman Long & Co. Ltd., to handle steel ingots heated up to 700° C. The magnet is provided with heat diverting shields and can be immersed in water for cooling purposes. Its weight is 27 cwts. and when operating on a 220 volt D.C. supply it has a flushing consumption of $3\frac{1}{4}$ kW which is reduced to $2\frac{1}{2}$ kW by means of a continuously rated series economy resistance which is inserted automatically by the contactor control gear. The load per lift comprises 4 steel ingots each measuring 6 ft. by 4 ins. square.

### COAL WASHING.

The successful washing of large coal in Great Britain has resulted in a contract from South Africa for a Chance Washing plant to deal with 235/300 tons per hour of 9 in. × 0 coal. This will be the first plant to wash coal of this size in South Africa and will also be the largest washer installed there. Hand picking will be entirely eliminated, as all coal above 9ins. will be broken to that size and sent to the washery.

### NEW TUNGSTEN PLANT.

Tungsten is a basic material in many branches of the electrical industry; in particular it is the very foundation of the electric lamp, whether filament or discharge. Consequently an adequate supply of pure metal produced by the most economical methods is of the utmost importance. An improved tungsten plant has been installed at Osram Lamp Works, Wembley, advantage having been taken of recent extensions to this works to lay out a section specifically designed in every detail for the particular chemical processes involved.

### ELECTRIC DISCHARGE LAMPS.

Two new types of high pressure mercury vapour electric discharge lamps were introduced during 1937. They are the 80 and 125 watt ratings for voltages from 200 to 260 and are supplied in pearl bulbs identical with those of the 150 and 200 watt tungsten filament lamps respectively. Their characteristics are given in the following table, which gives also, for the sake of comparison, the corresponding figures for other ratings.

**Fig. 31.—Fraser & Chalmers "Chance" coal washing plant at Ellistown Colliery Co., Ltd., Leicester.**

| Rated Lamp Watts. | Initial Lumens per Watt. | Average Lumens per Watt up to 1,500 hours. | Lumens per Watt at 1,500 hours. |
|---|---|---|---|
| 400 | 45 | 37 | 34 |
| 250 | 36 | 31 | 29 |
| 150 | 32 | 26 | 24 |
| 125 | 40 | 32 | 30 |
| 80 | 38 | 30 | 28 |

The two new lamps are fitted with bayonet caps which have three instead of two pins in order to prevent accidental use in normal sockets unprovided with choke protection. They can be burned in either the vertical or horizontal position. The other three wattage ratings, however, whose inner tubes are of hard glass, are intended for vertical operation only, and if they are burnt in a horizontal position their lives are shortened on account of the softening or cracking of the glass of the inner tube. During the past year, however, lamps of the 400 watt and 250 watt ratings have been made available on the market in a form suitable for burning in either

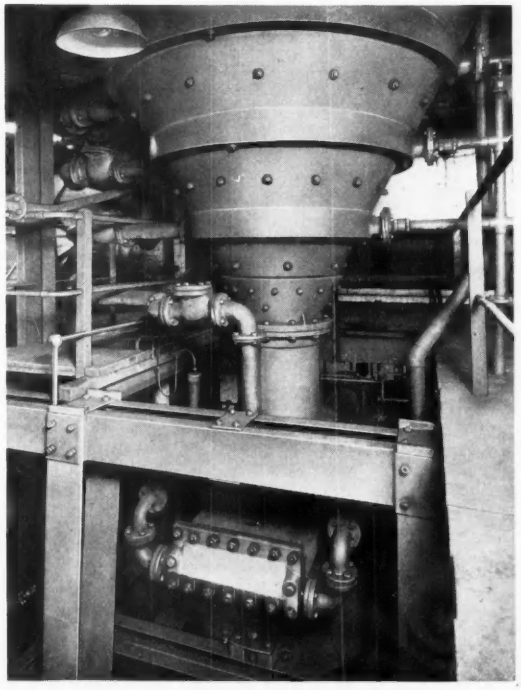


**Fig. 32.—Detail view of the base of the cone and classifier column of the Fraser & Chalmers "Chance" coal washing plant at Ellistown Colliery Co. Ltd., Leicester.**

position. The necessary slight alterations in the design result in efficiencies rather lower than those for the vertical burning lamp. The figures are given in the table below.

| Rated Lamp Watts. | Initial Lumens per Watt. | Average Lumens per Watt up to 1,500 hours. | Lumens per Watt at 1,500 hours. |
|---|---|---|---|
| 400 | 40 | 33 | 30 |
| 250 | 33 | 28 | 25 |

**A New Design of High Brightness Lamp for Floodlighting.**

When a lamp is used for purposes of projection, the two factors of importance are the shape of the source and its intrinsic brightness. The linear source obtainable with the high pressure mercury discharge is particularly suitable for use with the type of parabolic reflector at present in use in aerodrome floodlights. A 500 watt lamp has therefore been developed for this purpose. The inner tube is of quartz and the discharge is 100 millimetres long and some 1·5 millimetres wide. The brightness is greater than that obtainable with the present

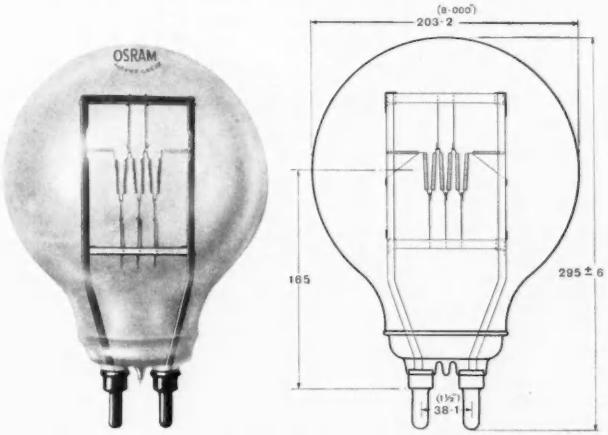



**Fig. 33.—Projection lamp for cinema studio lighting work.**

1,000 watt tungsten filament projection lamp and the overall beam intensity far higher than that obtained with the equivalent wattage of tungsten lamps.

**Luminescent Lamps.**

Osira electric discharge lamps have also been produced in luminescent bulbs having a red ratio of 5—6 per cent. These are made at present in the high voltage 400 watt rating only, and have special "Iso-thermal" bulbs, designed to obtain the highest efficiency from luminescent powders with which they are treated.

This lamp is intended chiefly for industrial use where colour is important; its characteristics are as follows:—

| | |
|---|---|
| Initial efficiency .. .. | 38 L/W |
| Average efficiency throughout life .. .. .. .. | 32 L/W |
| Efficiency at the end of 1,500 hours .. .. .. | 30 L/W |

A similar lamp is available in a tubular bulb for street lighting having the following characteristics:—

| | |
|---|---|
| Initial efficiency .. .. | 37 L/W |
| Average efficiency throughout life .. .. .. .. | 29 L/W |
| Efficiency at the end of life .. | 27 L/W |

### ARCHITECTURAL LAMPS.

Improvements made in this lamp include the removal of the exhaust pip from its exposed position on the bulb surface and its concealment beneath one of the brass caps. This has removed an obvious weakness and allows flush mounting when desired.

**Fig. 34.—"Pla-fractor" street lighting lantern.**

### CINEMA STUDIO LIGHTING LAMPS.

Studio lighting lamps are tending towards new forms. In projection work it is necessary to locate the filament accurately with respect to its reflector and this is facilitated by the use of "bi-posts" instead of Goliath Edison Screw caps. It will be seen at fig. 33 that the filament can be assembled exactly in position with respect to the posts before these are sealed into the bulb so that without further adjustment it will come into correct position in the projector. These lamps are obtainable in 2000 and 5000 watts ratings, and a 500 watt lamp will shortly be available.

### STREET LIGHTING LANTERNS.

New types of equipment have been designed for the small Osira 80 watt and 125 watt discharge lamp. The size and shape of many of these designs renders them suitable not only for these new lamps but also for Osram tungsten lamps, little modification being necessary.

The smaller Di-fractor lantern has been modified to make it suitable for use with the reduced dimensions of the luminous column of light of the new lamps, in exactly the same manner as the large Oxford lantern was converted for use with filament lamps.

An open type lantern, the "Pla-fractor" (fig. 34), was specially designed for the new lamps. The body consists of a single piece reflector-refractor of special G.E.C. heat resisting glass, the reflector portion being silvered, coppered, lead backed and weather resisting. The reflector contour is based on the design of the well known P.L.A. lantern whilst the prisms moulded on the bottom band are of identical design to those on the patent G.E.C. prismatic glass bowl refractor, and produce a 160 degree non-axial asymmetric light distribution. The prismatic refractor controls in plan the light which is reflected from the silvered portion of the glass as well as direct light from the lamp. The principle is similar to that used in the Oxford lantern, the reflector taking the place of the refractor. The unit has a semi-cut-off distribution and is intended for fairly close spacing with either 80 and 125 watt discharge or tungsten lamps.

A smaller edition of the Watford lantern (fig. 35) with newly designed refractor plates has been produced for use with Osira 150/250 watt lamps. The incorporation of an inner dome refractor will enable this lantern to be used with the new Osira low wattage lamps.

**Fig. 35.—Small "Watford" street lighting lantern for use with Osira 150/250 watt lamps.**

Another new unit is a wing type open directional reflector, the contour of which has been redesigned to give a better light distribution with a lower magnification. Two novel features have been introduced; the new fluting developed for the Gecoray reflector range has been added, and the whole unit, consisting of the two wings and the connecting part and neck, is blown in a single piece of glass. This unit is also suitable for either Osram or Osira 80 and 125 watt lamps.

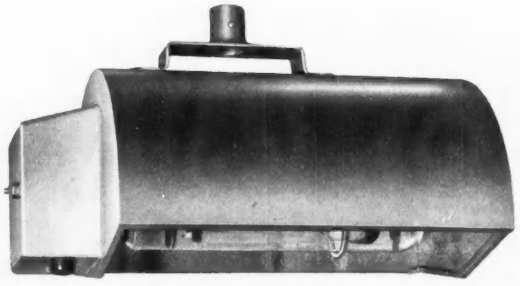


**Fig. 36.—Special street lighting lantern for use with Osira 250/400 watt horizontal lamp, giving a variable "cut-off."**

As it has been shown by tests that rain does not break the outer jacket of the Osira 80 and 125 watt lamps, outer globes are not necessary on this account.

The new Osira luminescent lamp is made in a cone-shaped bulb and also in a tubular bulb for use in certain street lighting lanterns and other fittings where perhaps dimensions will not accommodate the cone-shaped bulb. The special prism and flute combination, used in various ways in these lanterns, has the unexpected virtue that the large source of the luminescent lamp causes a much smaller fall in maximum intensity, as compared with the standard 500 watt lamp, than is found with some other prism systems.

Recent advances in glass technique have now enabled Osira 400 and 250 watt lamps to be burnt horizontally; for use with these a special lantern having a variable cut-off has been made. The light is controlled by curved mirrors, the angle of the cut-off being controllable by varying the position of the lamp relative to the lower edge of the lantern side. The light distribution of this lantern is such that at the accepted mounting height of 25 ft. the spacing should be approximately 90 ft. in a single row of units.

Where the width of the road and the permissible spacing are suitable, good results can be obtained with cut-off distributions provided that the power of the light sources is sufficient. This unit (fig. 36), gives excellent results so long as the design conditions are adhered to, and provided the extra expense of such installations can be met, it provides street lighting of a quality not previously available.

Hitherto, cut-off units have been of low power, and the results have been dull. The extra power available in the 400 watt lamp has given much more satisfactory results. The result of too great a spacing is the production, due to the cut-off, of black bands across the road. This method of lighting is only recommended where a definite cut-off is desired and can be afforded, as the closer spacing necessitates a greater number of units, and therefore a higher running and capital cost.

In connection with the Di-fractor lanterns and the lanterns of the Watford, Lewisham and Tunbridge Wells types, two new developments in glass have been made. For the heat-resisting glass pressings a new glass has been developed, which has not only a longer working range than the glass previously used, but has also a considerably higher resistance to thermal shock. This makes these heavy refractors immune from cracking in sudden rainstorms; although the older glass gave very little trouble in this respect, exceptional conditions could cause a crack. For the square lanterns, a new design of rolled glass has been developed in conjunction with a glass manufacturer. This is a lined glass intermediate in properties between the "luminating" and the "lined plate" glasses previously used.

A further development in street lighting is the production of wax-filled chokes which are being used with Osira 80 and 125 watt lamps; the

**Fig. 38.—Osira 400 watt lamps used for street lighting in Birmingham, where the largest discharge lamp street lighting installation in the world has just been completed.**

**Fig. 37.—80 watt Osira lamps used for street lighting at Musgrove Road, Deptford, London. The Osira lamps are fitted in small Oxford lanterns.**

G.E.C. is the only firm to manufacture chokes with this feature. Such chokes possess several operating advantages, for instance, the setting remains constant, the whole choke being immersed in wax; it is protected from damp, dirt and dust, and it is noiseless in operation. This feature of wax-filling will be extended to the higher wattage range of chokes.

### STREET LIGHTING EXTENSION.

Considerable extensions in street lighting have been made, and there are now between 600 and 700 miles of road lighted by Osira high pressure mercury vapour discharge lamps in Great Britain.

**Fig. 39.—6 kW, 6-lamp aerodrome floodlighting unit at Singapore.**

Many installations have been undertaken and completed, Birmingham and Deptford being perhaps the most interesting.

Birmingham has now the largest lighting installation using discharge lamps in the world (see fig. 38); approximately 150 miles of main arterials, through traffic and bus routes, and circular link roads being lighted by Osira discharge lamps and Osram tungsten lamps contained in Birchfield and Di-fractor lanterns. The installation of this enormous contract was undertaken by the G.E.C. and completed in six months.

Deptford will be the first borough to be lighted throughout by Osira discharge lamps (see fig. 37). Every size of Osira lamp is being employed, the low wattage 80 and 125 watt in the side roads, and 250 and 400 watt in the main roads and through roads. For this installation a special design of spun concrete column was produced. The scheme when completed will cover some 50 miles of streets.

The theory of street lighting based upon the importance of the brightness of the road surface as propounded by the G.E.C.[5] continues to gain ground and is now generally accepted as being the correct principle.

### AERODROME LIGHTING EQUIPMENT.

As an alternative to the use of aerodrome floodlights some pilots prefer to land by a series of "marker lights" sunk in the ground, defining the line on which they are to land; they have the advantage of giving the pilot a definite mark. A special unit has been designed with a mirror interior giving a maximum intensity near the horizontal and a toughened glass front which will withstand shock from a tail-skid. The units are intended for use with a 6·6 amp. series lamp, and an isolating transformer is included in the case.

For giving an indication of the character, force and direction of the wind, a smoke indicator has advantages over a "wind sock" or tee. It is usually placed in the centre of the aerodrome, and the smoke has usually been produced by vaporising oil by an arrangement using a pressure oil burner. This works well, but it is necessary to visit it during the day to pump up the pressure and adjust the oil flow. A smoke generator which can be controlled from the control tower would have great advantages. It was found to be surprisingly difficult to produce a reliable electrical smoke indicator, but an apparatus has now been developed at the Research Laboratories in which oil is sprayed on to an electrical hotplate, where it is vaporised and the vapour blown out by a fan. The apparatus may be controlled by a cable from the control tower.

Jersey and Singapore aerodromes (fig. 39) have been equipped during the last twelve months. The most important item for both these aerodromes was the 6 kW 6 lamp floodlight with its moulded "Uraston" housing. Owing to the success of the floodlights at Jersey, the consulting engineers responsible have also ordered these floodlights with housings for Begumpet Aerodrome, Hyderabad. Another item of interest at Singapore is the illuminated buoy equipments for the seaplane channel. A special buoy equipment was designed (fig. 40). The body consists of a straight sided sheet copper cone. Within this is a cast iron box containing a small isolating transformer. The head of the fitting consists of a cast naval brass top, surmounted by an amber glass. A plated reflector of special contour is used, fitted underneath with a circular armour plate glass and a glass amber coloured screen. A 6·6 volt 6·6 amp. series burning Osram lamp is positioned at the focal point of the reflector. The lamp provides light through the amber top from 5 degrees below the horizontal to the zenith and through

5.—"Road Surface Reflection Characteristics and Their Influence on Street Lighting Practice," G.E.C. Journal, Vol. VI., No. 2, May 1935, p. 67.

360 degrees in azimuth; it also illuminates the straight sided sheet copper cone with amber light. The lamp is fed from the secondary side of the isolating transformer. The whole fitting is mounted centrally and on top of a floating concrete buoy (fig. 40). Thirty-six of these units were ordered for Singapore, forming a double channel of 18 fittings on each side. These are believed to be the first night lighting facilities provided for seaplanes and flying boats.

The increasing development of night flying has been made possible by the increased suitability of navigational instruments and by the increased facilities provided on landing grounds in the way of lighting improvement and also by lighting improvements in the aircraft itself.

However well equipped for night landing the aerodrome normally used may be, there is always the possibility of a forced landing being necessary, away from the lighting facilities to be found upon them. In the past the solution of this difficulty had been sought with flares of various descriptions, mounted under the wings of the aircraft. This, however, was a temporary expedient owing to the very considerable danger of fire.

The emergency landing problem has now been met safely by the the introduction of the electric aircraft landing light, which imposes no added strain through fear of fire upon the pilot, at a moment when he may least be able to bear it. Lights for this purpose are made in varying types, according to the nature of the service required and the size of the aircraft. They may be fitted in four positions in an aircraft :—

(*a*) in the nose, in the case of a twin engined aircraft.

(*b*) in the leading edge, in the case of either a twin or single engined aircraft.

(*c*) fitted flush with an underneath side of the wing and made retractable.

(*d*) fitted in front of the wheel "spats" on the undercarriage.

Progress in the design of Osram landing lamps has led to considerable demand for them from the Air Ministry and manufacturers of aircraft landing lights. A typical installation of the nose type landing lamp is shown in fig. 41 whilst the fitting of the retractable type is shown in fig. 42.

There are at the moment four standard types of aircraft landing lamps available, these are :—

12 volt 12 amp. Single Filament Prefocus Cap.
12 „ 12 „ Double „ „ „
9 „ 15 „ Single „ „ „
9 „ 15 „ Double „ „ „

It is interesting to note that Imperial Airways have specified Osram aircraft landing lamps for use on the Empire flying boats. Moreover, these lamps were used exclusively in the "Caledonia" and "Cambria" when engaged upon the Trans-Atlantic flights during the summer of 1937.

### CINEMA STUDIO LIGHTING.

Many forms of optical system have been studied with the object of producing the ideal economical form of lighting unit for cinema studios, and as a result two new specialised units have been added to the existing extensive range.

The first unit was developed by Research Laboratories and employs a square plate prismatic lens backed by a fixed diaphragm, to be used in conjunction with a flat grid filament studio projector lamp and a spherical glass backing mirror. The unit is square, and is built up from aluminium castings. A double pole switch is mounted in a switch cover which when screwed to the unit automatically clamps the trailing cable. The complete unit is mounted on an off-setting cradle, which has a socket base to take a standard $1\frac{1}{8}$in. spigot for mounting on stand or spot-rail.

This projector has been designed to give the maximum possible spread of even illumination, and this is about 12ft. in diameter at a distance of only 10ft., while the unit may be focussed down to a spot of 3ft. 6ins. diameter. It has the special characteristic that it gives hard sunlight shadows at any degree of spread.

**Fig. 40.—One of the 36 illuminated buoys installed at Singapore to mark a seaplane channel.**

The second unit, fig. 43, which has been developed is intended to meet the requirements of the studios which demand both high intensities in the spot position of their set illuminators, and a comparatively large spread of light. For this purpose a mirror of special contour has been developed which, when used in conjunction with a flat grid filament studio projector lamp and a diffusing front glass, gives a very high intensity. It is possible to obtain an illumination of 6,500 foot candles over a spot of 2ft. in diameter, and by focussing the lamp forward to produce a spread of even illumination eight feet in diameter at a distance of 10ft.

**Fig. 41.—Nose type landing lamp for mounting in the nose of twin-engined aircraft.**

**Fig. 43.—2 kW Cinema studio lighting unit.**

The unit is composed of two large aluminium castings and is spherical in shape. A louvre is fitted to the front of the lamp carriage in order to eliminate spill light.

The focussing handle is heat-insulated, and folds into the focussing wheel, which is protected by the body casting. For the purpose of hoisting this unit to the spot rail or other elevated position a hoisting ring is countersunk in the top of the body. The ring, when not required folds out of the way. The body is mounted on a fixed tubular cradle and clamped with a large hand wheel designed to conform with the lines of the body. This unit weighs only 40lbs. and therefore may be handled easily by one person.

Further designs are in course of development.

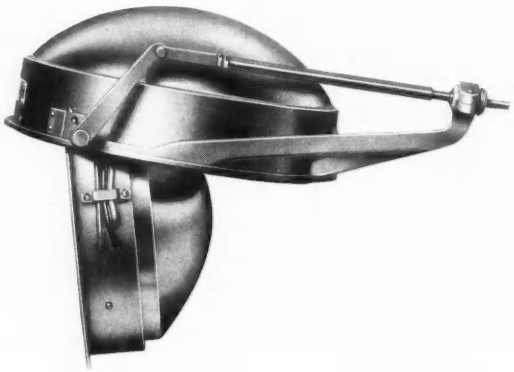


**Fig. 42. Aircraft landing light of the retractable type for fitting flush with the underneath side of the wing.**

#### Decorative Lighting.

Decorative lighting has developed on normal lines without revolutionary change in lighting practice. In decorative design the tendency is towards a freer line and less formal treatment. In built-up fittings the importance of efficient and planned light control is becoming more and more recognised, and reflecting equipment which gives either indirect or downward directional lighting components is an essential part of many built-up modern fittings. Indirect lighting grows in popularity but it is more generally recognized that to overcome the tendency to monotony high lights must be provided. In many cases these high lights are obtained from bulls-eyes or glass inserts let into the bottom of the cornice or indirect fittings used for the main lighting. In other cases they are obtained from auxiliary equipment such as wall brackets provided solely for their decorative effect,

Fig. 44.—An example of shop lighting by means of diffusing glass fittings specially designed to give high intensity illumination on the sales counters.

and not intended to contribute materially to the general illumination.

INTERIOR AND SHOW WINDOW LIGHTING.

The range of Gecoray reflectors has been completed by the design of a "demi-coupe" unit intended for wall mounting for the indirect lighting of ceilings and vaults. The design of this unit presented unusual difficulties as it was essential to provide accurate control of the light, and also to prevent bare light from the lamp making an unpleasant bright area near the fitting.

The improved fluting specially developed for Gecoray reflectors is now used on nearly all the units in the range, and is designed to produce sufficient diffusion without interfering unduly with the distribution. The use of a poorly designed fluting can seriously impair the efficiency of a reflector.

A cheap unit has been designed for show window lighting in which two or three lamps are arranged

Fig. 45 (above).—Decorative lighting fittings in the new show rooms of the City of Oxford Electricity Dept.

Fig. 46 (left).—Specially designed high efficiency decorative lighting pendants in D. H. Evans' new store in Oxford Street, London.

within a single trough reflector. This unit is particularly useful when it is desired to mix the light from tungsten lamps with that from the Osira 80 or 125 watt lamps. These lamps can also be used in the standard Gecoray show window type reflectors.

Improvements have been effected in the 36-inch hospital operating theatre fitting, and a

**Fig. 47.—White and gold Osira fluorescent tubes are specially blended to show flowers in their natural colours at Lyons' Corner House, Coventry Street, London.**

24-inch fitting of this type has been produced. An 18-inch fitting is being designed for ophthalmic and dental work.

### OSIRA FLUORESCENT TUBE LIGHTING.

A number of new colours have been developed for fluorescent tubes. Several of these are being employed commercially; they include (*a*) a pale blue, with a luminous efficiency about twice that of the best blue colour hitherto used, and about six times as efficient as a plain mercury tube; (*b*) a pale pink colour with a very good efficiency. This colour is of particular interest owing to its very good lumen maintenance in the mercury discharge; (*c*) a cream colour which, while unsuitable for use alone for interior lighting purpose, makes a very fine white tube for advertising work. Several other very attractive colours can be obtained using the same powders combined with coloured glass tubing.

Two new interior lighting combinations have been standardized. These employ white, pink and gold colours and give a resultant light somewhat resembling daylight in its general qualities. The overall luminous efficiency of these units is considerably better than that of tungsten lighting. In certain Osira fluorescent tube combinations, a change in the quality of the resultant light occurs owing to the poorer lumen maintenance of one of the colours. A special variable choke has been developed for ensuring constancy of colour during life. A new method of connecting high voltage transformers in discharge tube circuits has been developed. In this the usual large leakage reactance transformer is replaced by two or more much smaller transformers. The great advantage of this in the case of interior lighting installations is that it is now possible to make a self-contained unit in which the high voltage transformers are located in the electrode boxes. All external high tension wiring is thus eliminated. Improvements have also taken place in the design of dimming equipment, whereby better and more even dimming can be obtained, particularly on the red tubes.

**Fig. 48.—Osira fluorescent tubes give the necessary high intensity evenly diffused lighting in the gauge room of an aeroplane factory.**

Interesting installations carried out include one for the fruit and flower shop in Lyons' Coventry Street Corner House, fig. 47, where a combination of white and gold tubes has been selected to show the flowers in their natural colours; while a number of installations of a strictly utilitarian nature have also been completed. These are for the gauge rooms of some of the principal aircraft factories, fig. 48, where the requirements are high intensity illumination of a relatively shadowless nature such as will reduce fatigue to inspectors working permanently under artificial light on a type of inspection calling for a very high degree of

concentration. In addition to the above qualities, minimum heat generation was required, and such heat as was generated had to be dissipated as evenly as possible throughout the room. It was found that a combination of white and pink tubes installed visibly on the ceilings of the gauge rooms fulfilled requirements in a way which no other known light source would appear to equal. The low surface brightness of the tubes allowed them to be installed visibly in such a way that their full high efficiency as light sources could be taken advantage of, while the fact that the tubing was distributed evenly over the whole ceiling of the room automatically ensured even heat distribution. The colour quality of the installation was psychologically as near as possible to sunlight. Similar installations have now been completed in several aeroplane factories.

**Fig. 49.—Ballroom of the Piccadilly Club, Glasgow is lit with a combination of concealed Osira fluorescent and decorative tungsten lamp units.**

INDUSTRIAL LIGHTING.

Further advances have been made in the use of Osira high pressure mercury lamps in industry. The introduction of the 80 and 125 watt lamps with corresponding ranges of reflectors has widened the field by allowing Osira lighting to be installed in places where, owing to the limited mounting height available, the higher wattage lamps were impracticable.

In conjunction with Benjamin Electric Co., Ltd., new reflector designs have been perfected during the year. The most important of these is one which while embodying the features of the Saaflux top introduces an overlamp device of a dust-tight nature. Consequently this reflector, in conjunction with a dust-tight visor front, can be used advantageously in conditions where excessive dust or noxious vapours are present. Another type of reflector has been designed on less expensive lines but still retaining special features to protect the overheating of current leads. Both of these types have been introduced in various shapes corresponding to those mostly in demand for standard industrial lighting work.

The advent of the 400 watt luminescent lamp opens still further the field for industrial Osira lighting in processes where greater colour discrimination is required in the red end of the spectrum than it is possible to obtain from the standard Osira high pressure mercury lamp. Such processes include the manufacture of fine cables or the wiring of wireless and similar equipment to a colour code where, with the ordinary type of Osira lamp, the discrimination between certain shades of brown and red flexibles was insufficient.

Flameproof lighting fittings embodying tungsten lamps have been introduced, and in addition to

**Fig. 50.—Osira lamps used for lighting a modern steelworks.**

increasing the range of flameproof pendants, a special 500 watt narrow beam flameproof floodlight has been perfected and certified by the Mines Department Testing Station for use in petroleum vapour and similar atmospheres. A considerable quantity of these floodlights has already been supplied for use in oil plants and storage depots.

Coronation celebrations were the cause of great activity in floodlighting. Many installations were carried out both at home and in the British Dominions and Colonies. The range of floodlighting

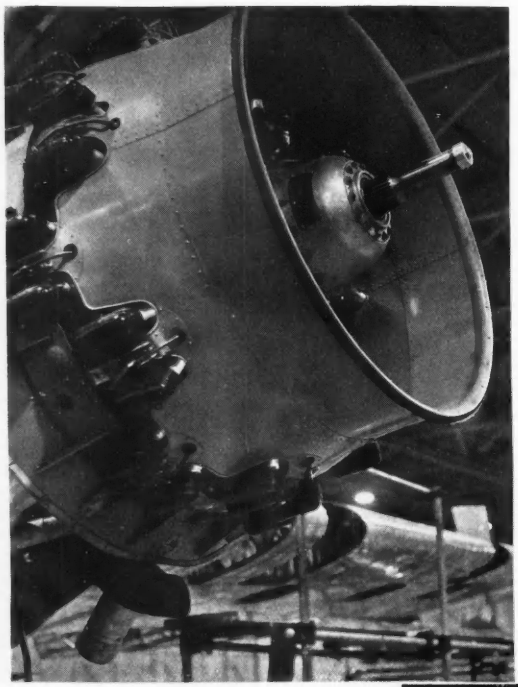


**Fig. 51.—A noticeable feature of the lighting obtained with Osira lamps is the manner in which light appears to be reflected off walls and floor as illustrated by the illumination on the underside of the aeroplane engine shown in this picture.**

equipment was increased by the introduction of a unit to take the 400 watt high pressure mercury lamp burning in a horizontal position without deflector.

### CLEORA FLUORESCENT TUBES.

In connection with this range of discharge tubes, manufactured by Claude-General Neon Lights, Ltd., improvements in the fluorescent powders used for coating the inner wall of the glass tubes have been effected, resulting in a general increase in output and higher efficiency of light output from the tubes. New colours have been added to the range notably some new shades of off white. Fluorescent tubes are being run at a current of 0·5 amperes as compared with the normal 60 milliamps.

### HIGH INTENSITY TUBING.

A tubing of 7 mm diameter tubing at a high current density has been produced; it is styled high intensity tubing and is particularly suitable for the outlining of letters and the making of very small letter signs which present a very neat appearance. The colours available are red, blue and green.

### DESIGN OF SIGNS.

An interesting form of letter carries a stepped edge on its front face to which is fitted high intensity blue tubing. The rear face is arranged to carry an amber fluorescent tube made in reverse, the purpose of which is to illuminate the background in a contrasting colour.

Another type of letter recently introduced is known as "The Shadow." It is cut out from thin sheet metal and the tube is semi-recessed. The metal letter is set out from the background which throws the letter into silhouette, and this in turn is illuminated at its centre by the front face of the tube.

A rainbow effect for interior lighting has been produced. This is obtained by interrupting the light rays from fluorescent tubes situated in a cove by means of suitably shaped and positioned wood slats. These can be arranged to be shifted mechanically, the result being a cyclic effect of colour change.

The use of lenticular glass for background work on large signs and in small signs of the box

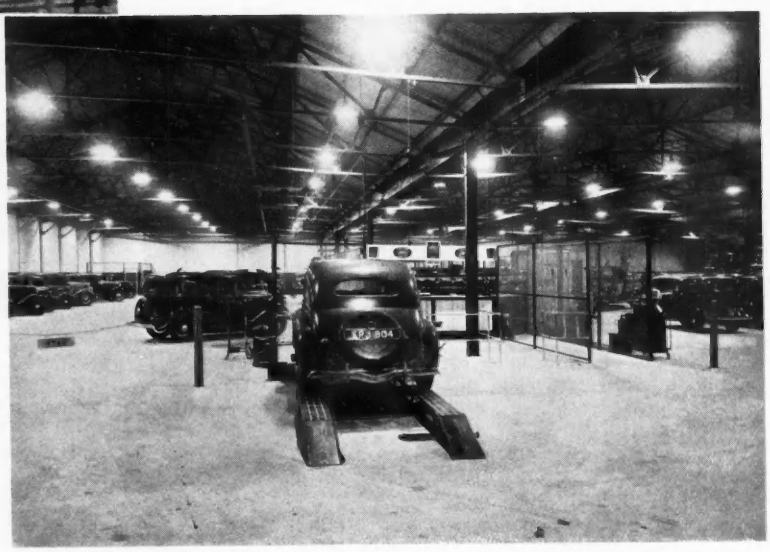


**Fig. 52.—Osira lamps provide the ideal light for a motor service depot. An installation at Lambert Motors, Ltd., Ford distributors of Kingston-on-Thames.**

type is increasing. There is a big demand for "L-type" signs and a new design of this incorporates a clock movement which materially increases the advertising value of the sign.

London Electric Supply Co., Ltd. Super-tension cable has been provided for the Cardiff Corporation.

In connection with the lighting of 150 miles of Birmingham streets by Osira lamps, installation work was undertaken which included the erection of lamp posts, lanterns and the conversion of existing tramway standards.

**Fig. 53.—The first installation in the world of the new luminescent discharge lamp. The Victoria Coach Station of London Coastal Coaches, Ltd., illuminated by Osira luminescent lamps.**

### HIGH VOLTAGE LINE INDICATORS.

The neon discharge tube is now used in this country as an indicator to aircraft of the presence of H.V. lines.

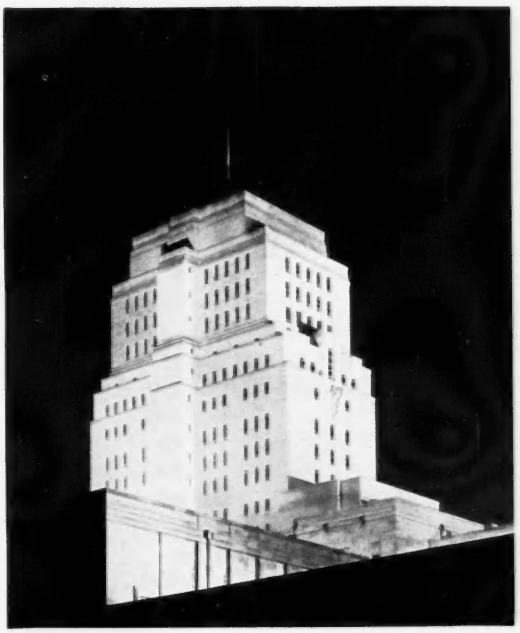
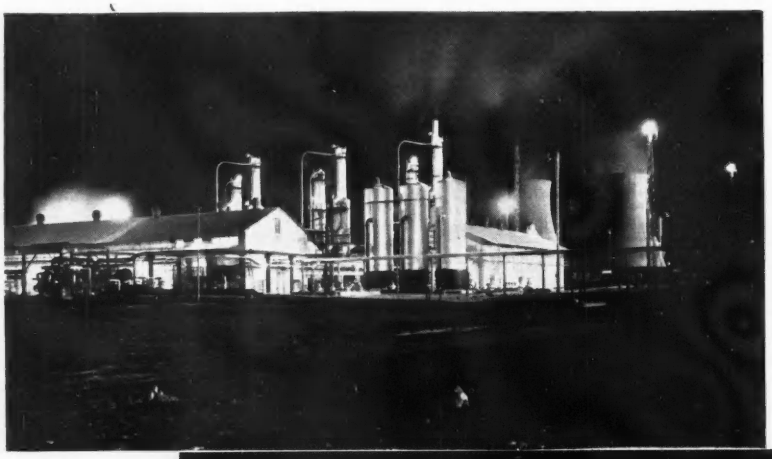


**Fig. 54.—The tower of the new London University Building floodlighted on the occasion of the granting of an honorary degree to H.M. the Queen.**

### SUPER-TENSION CABLES.

The electrification of various sections of the Southern Railway has led to contracts covering 348 miles of single core 33 kV cable with supervisory control gear and pilot cable. The 231 miles of the cable for the Havant to West Worthing, Ford Junction to Horsham and Three Bridges, and Horsham to Dorking lines have been installed and tested; while the remainder, for the Guildford-Reading line, is likely to be finished by June, 1938.

Over 12 miles of 66 kV 3-core oil-filled cable have been completed for the Central Electricity Board, and a further scheme concerned with oil-filled cable has involved the removal of existing oil-filled and solid type 66 kV cables from the Old Wandsworth Bridge, and the re-laying of new cable on the temporary footbridge (fig. 59). The new cable consisted of two 3-core 0·35 sq. in. 66 kV oil-filled cables, each 450 yards long in one length and weighing 17 tons (fig. 59). Oil-filled cable has also been ordered by Edmundson's Electricity Corporation for the Shropshire, Worcester and Staffordshire Electricity Supply Co., Ltd., and also by the County of



control point from which radiated the outgoing cables to four stepdown transformers.

From the main 400/230 volt distributors, temporary lines were carried for floodlighting the site as required during the progress of the work, and 5 kVA 230/100/50 volt transformers were provided for affording a safe supply to portable apparatus.

**Fig. 55 (left).—G.E.C. Floodlighting enables work to be carried on as well by night as by day in the Mesopotamian desert. An installation at one of the Irak Petroleum Co.'s. plants.**

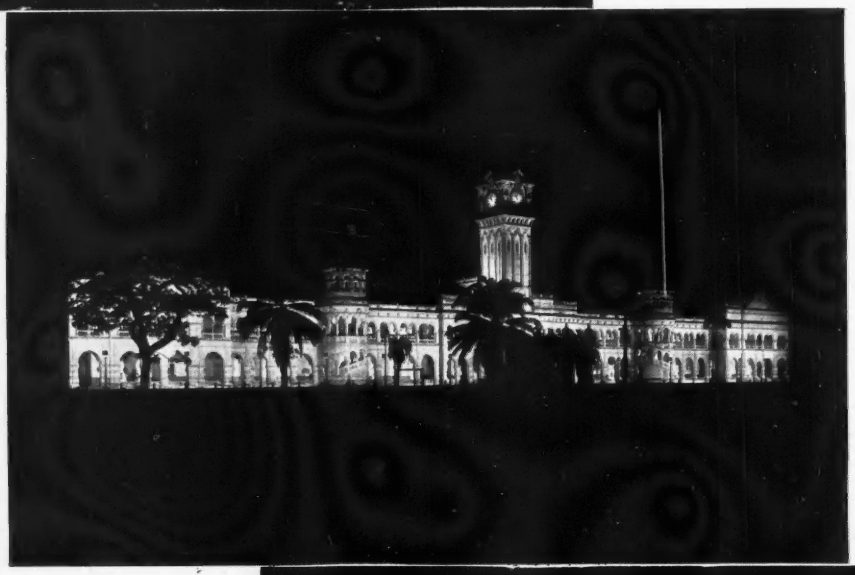


**Fig. 56 (above).—Government House, Kuala Lumpur, floodlighted on the occasion of the Coronation of H.M. King George VI.**

## OVERHEAD LINES.

A temporary overhead distribution scheme for the lighting and power supply for a large civil engineering contract in Lancashire presented unusual features. The amount and location of the load necessitated an E.H.T. supply with four feeding points within the site. Owing to the nature of the work, underground cables and bare overhead conductors were both desirable for this supply and Pirelli-General catenary cable was therefore employed. The cable was carried on the poles which carried the distribution wires and the system was laid out to provide a central

**Fig. 57.—The light colouring and pronounced architectural features of many buildings in tropical countries are peculiarly suited to floodlighting. The Malacca Hospital, Singapore.**

TELEPHONE CABLES.

The building of an entirely new factory at Eastleigh for the manufacture of all types of telephone cable is nearing completion. Some distance away from the main building is a specially constructed block which will serve as the testing rooms. This is equipped with the most modern instruments and has been detached from the main building in order that the vibration of the plant and machines may not interfere with the sensitiveness of the testing apparatus. The test building includes also a high frequency research laboratory. The whole extension provides a complete and separate unit entirely devoted to the manufacture and testing of telephone cable, and existing plant has been modernized so as to cater for increase of output of a high quality product. The Pirelli-General type of continuous lead extruding machines have been installed for the lead covering of cables.

The new factory greatly facilitates the execution of emergency orders; as an example may be mentioned a contract for the supply and installation of a submarine cable between Portsmouth and Gosport for the British Post Office. The cable had to be installed and brought into service within seven days; this task was satisfactorily accomplished (see fig. 61).

Fig. 59.—Laying 66 kV oil-filled cable along the temporary footbridge of Wandsworth Bridge.

Fig. 58.—Fluorescent tube lighting at the Gaumont Cinema, Camden Town, London.

WIRE ROLLING MILL EQUIPMENT.

The rolling mill equipment at Eastleigh has been extended to undertake the manufacture of cold rolled cadmium rods for drawing to high tensile wire for overhead line construction and Post Office purposes.

RUBBER INSULATED CABLES.

The C.M.A. introduced new standards for rubber insulated cables on January 1st, 1937, and Pirelli-General Cable Works, as a member of this association, took an active part in their preparation. In recent years very considerable advances in rubber technology have been made in relation to the application of vulcanized rubber for electrical insulating purposes; therefore, in formulating these new standards only improvements thoroughly proved by experience have been incorporated.

The layer of pure rubber formerly applied adjacent to the conductor has now been abandoned. Experience has shown that it was generally the first portion of the composite insulation to deteriorate. Improvements achieved in rubber compounding and vulcanization technique have resulted in the production of vulcanized rubbers which can be applied with safety directly on to the conductors without the necessity of using the layer of pure rubber as a protective barrier between the wires and the vulcanized rubber.

The radical changes which have occurred in rubber compounding have made the insulation resistance test of little value as an indication of the

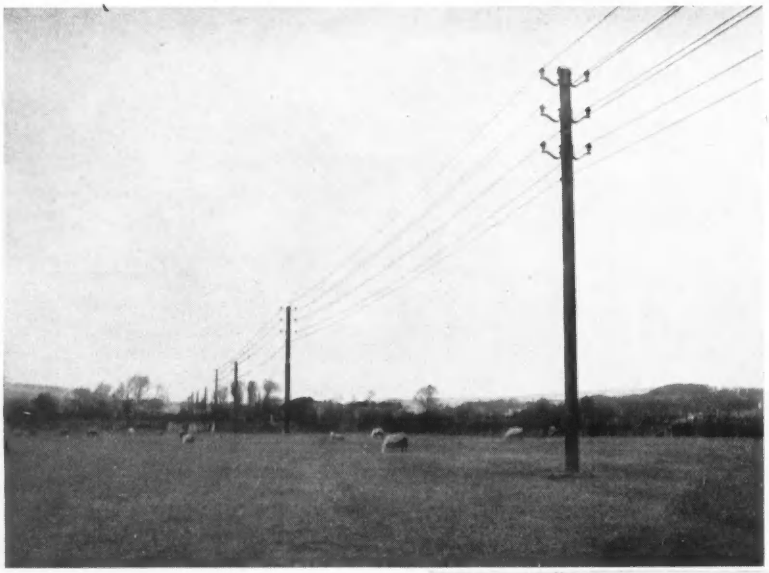


**Fig. 60.—Double circuit 11 kV overhead line erected for Powell Duffryn Associated Collieries in S. Wales.**

reliability of a rubber insulated cable; therefore, classification by megohms has been discontinued, the cables now being classified by the voltage at which they are designed to operate.

Consideration has been given also to details of all component parts of the finished cables, such as tapes, braids, lead alloy, tough rubber sheathings, protective compounds, etc. For these, standards have been laid down to ensure a uniform level of high quality. The new standard dielectric, combining the best characteristics of the pure and V.I.R. type with outstanding physical and chemical properties is the result of prolonged effort to resolve a standard dielectric suitable for the modern working conditions of rubber insulated cables.

Considerable extensions to the Southampton Works have been put in hand, which are an addition to these referred to previously in the *G.E.C. Journal*[6] When these are completed the total area will represent an increase of over 50 per cent. Such progress is the more striking when it is remembered that until 1927, the works at Southampton were devoted to both rubber cable and paper cable manufacture, whereas to-day, the activities at Southampton are devoted solely to rubber and flexible cable manufacture, and the production of instrument and dynamo wires and strips. The Eastleigh Works is an entirely separate unit covering many acres; as indicated above it is concerned with the manufacture of paper insulated cables (power and telephone) and the production of copper wire, rod and strip.

### NEW COMBINED TELEPHONE AND EXTENSION SWITCH.

A notable addition to the range of subscriber's apparatus has been made by the introduction of a new combined telephone and extension switch, suitable for use as a main-station instrument in conjunction with an extension telephone, in a manner which provides inter-

**Fig. 61.—Laying a length of 840 yards of submarine cable for the G.P.O. This cable was made and laid in seven days to meet urgent requirements.**

connection between exchange and main, exchange and extension, and main and extension. It thus replaces the switching bell set which, although having given good service for many years, does not conform to modern ideas of combined utility and pleasing appearance.

The new self-contained instrument for use at the main station gives a marked improvement over previous practice in which a separately-mounted switching unit was necessary in addition to the main telephone. The four-position switch, controlling the various interconnections, is now incorporated in the base of the telephone (fig. 62). In addition, a considerable improvement has been effected by

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arranging for the local battery at the main station to supply the current for calling between main and extension telephones, thus dispensing with hand-generators. Interstation calls in either direction are signalled by means of buzzers mounted inside their respective telephones and operated from this battery. Provision may also be made for two extension telephones, selectively called by means of push buttons incorporated in the main-station instrument.

The bell associated with the main telephone for signalling calls from the exchange is mounted separately thus making the telephone standard for use with a normal bell or one of the loud-ringing pattern if desired.

The circuits of the two instruments are based on that of the Gecophone set, employing the latest pattern anti-side tone induction coil. The transmitter, receiver, dial and coil are all standard and interchangeable with Gecophone parts. A suppression circuit is associated with the buzzer to minimize the possibility of interference with radio. A relay, mounted in the base of the main-station telephone, is held operated during calls between exchange and extension and displays a visual "engaged" signal through a glass-covered aperture in the base.

When required for manually-operated telephone systems, the dials are replaced by dummies, while for tropical service, materials and finishes are specially chosen for resisting adverse climatic conditions.

### TELEPHONE EQUIPMENT ON BOARD SHIP.

A realisation of the need for a comprehensive telephone system aboard large passenger vessels is now general and an exchange of considerable proportions is regarded as an essential feature of modern ships. The circuits and apparatus employed are well established in telephone practice and the provision of communication on board involves their best application rather than the development of new methods. Progress, therefore, has been confined to changes calculated to increase passenger convenience, or to reduce the quantity of apparatus.

Two innovations have been incorporated in the telephone equipment supplied for the s.s. *Stratheden*, the new vessel added to the P. & O. fleet. The telephone is used on board by passengers requiring service of any kind—each cabin being equipped with an instrument. The system provides also for inter-communication between the staff, whilst, in addition, calls may be made from cabins or booth over shore lines when the ship is in port.

Manual operation was chosen in order that the passengers could obtain immediate contact with the service staff without the necessity for consulting a directory. The effort required of a passenger in calling is thus a minimum, but it may be more than he or she feels capable of making if indisposed. Therefore at the head of each berth is fitted a push which, when operated, causes the line lamp to flash in front of the operator. This signal, being different from that received on a call from a telephone, denotes to the operator that a member of the service staff should be instructed to attend at the cabin. On entering the cabin the attendant presses a reset push to stop the flashing signal.

Whilst this service could have been provided very simply over a second pair of wires to each cabin, in actual fact it is obtained over the same pair of wires that link the telephone to the switchboard thus introducing considerable economy in line wires.

The second change from previous practice lies in the use of a high resistance lamp for line signalling,

**Fig. 62.—New combined telephone and extension switch.**

having the characteristics that its resistance varies considerably with the current through it, whilst the light emitted remains sensibly constant. It is therefore connected in series with the line and dispenses with the need for line relays.

### GECALLOY CORES.

To meet the increasing demand for compressed dust cores, a new and larger core department has been built and equipped at Salford Instrument Works. It contains the latest type of powder and core making machinery and apparatus for the manufacture of Gecalloy cores from raw materials, and the material can be tested at various stages in its manufacture by modern equipment developed in the works.

The number of loading coils supplied for underground telephone lines has increased considerably compared with last year's total and in addition a large number of filter coils for carrier telephone equipment have been manufactured. The radio core business has assumed considerable dimensions; besides a large number being used in the G.E.C. organization, many of the largest radio manufacturers have also been supplied with Gecalloy radio cores of various sizes and designs, and there has been a considerable demand from overseas.

About thirty different types have been developed for all purposes.

RADIO RELAY.

The cost of the central receiver on a radio-relay system is virtually shared by subscribers to the service. Therefore it has always been possible economically to install a high-class receiver to give reception of a standard which individuals—were they not subscribers—would probably be unable to afford. To no small extent this has been a factor in promoting the popularity of relay services and it was realised that there was justification for an even better receiver than those normally available.

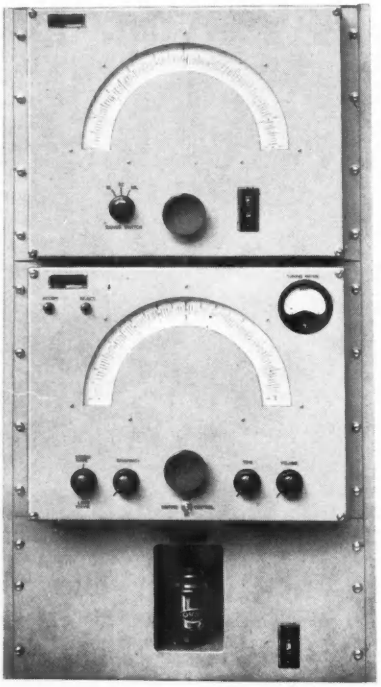

**Fig. 63.—Nine valve radio relay receiver.**

Certain development work has been completed and the result is a receiver which it is confidently anticipated will prove one of the finest in commercial production. It is illustrated in fig. 63, and incorporates nine valves, without L.F. amplifiers, together with seventeen tuned circuits. The set employs the super-heterodyne principle and has been designed to give the best compromise between the conflicting requirements of quality and selectivity. The wave ranges covered are 200 to 550 metres and 900 to 2000 metres with a band width of 9 kc. A separate self-contained unit supplies the necessary power from A C. mains.

Tuning is effected by two-speed drive and the large dial is read in conjunction with calibration curves. Muting to give silence between stations may be switched in or out of circuit and does not produce distortion. Automatic volume control limits the output variation to 3·5 decibels with a signal variation of 5 decibels, whilst over a low-frequency range of 50 to 6000 cycles, the variation in output is no more than $\pm$ 2 decibels.

A sensitivity control is provided, and when it is set at maximum, the muting circuit accepts at an input signal of 4 microvolts on 1000 kc. Intermediate positions of the control enable the sensitivity to be reduced in order to reject unwanted signals. In the muting circuit, acceptance is indicated by a lamp signal, coloured green, whilst rejection is denoted by an alternative lamp, coloured red. A tuning meter indicates the actual signal strength. In addition, a short-wave converter has been designed for use with the receiver to cover wavebands down to 12 metres.

AXLE COUNTING EQUIPMENT.

It is well known that the track circuit forms a basis of protection in modern railway signalling practice. There are places however where a track circuit will not operate reliably, such as tunnels where the ballast is very moist, moreover steel sleepers preclude the use of track circuits altogether. To meet these conditions there has been for some years a demand for a reliable axle counting equipment and The Siemens and General Electric Railway Signal Co., Ltd., have recently introduced such an equipment on the home railways.

The individual items of equipment for a section of line consist of two multi-spring treadles and a counter unit. One treadle is clamped to the rail at the entrance and the other treadle at the end of the section. When a train passes over the section, the entering treadle is contacted by each passing wheel which causes the counting mechanism to move off normal and record the number of axles that have passed. The mechanism remains thus until the train passes over the leaving treadle, and if the same number of axles are counted out as were counted in the mechanism returns to normal and indicates on its control contact "Section clear."

A typical treadle is shown in fig. 64. The design of the wheel contacting means is essentially novel; it consists of six sets of transversely mounted leaf springs in which no pivots of any kind are used. The springs are assembled on to a welded steel housing and the completed assembly is clamped to the inside of the rail. The flange of each train wheel passing over the treadle depresses the springs in a regular sequence, and the movement so given operates electrical contacts mounted in a compartment at the top of the treadle.

Fig. 65 illustrates a counter unit, which consists of one or two step-by-step rotating field motors, the armatures of which are caused to rotate in response

to the electrical impulses produced by the operation of the treadle springs. A double motor unit is employed where it is possible to operate both the entering and leaving treadles simultaneously, and with this arrangement the two motors are coupled together with differential gears which operate the control contact and a Veeda type counter indicator

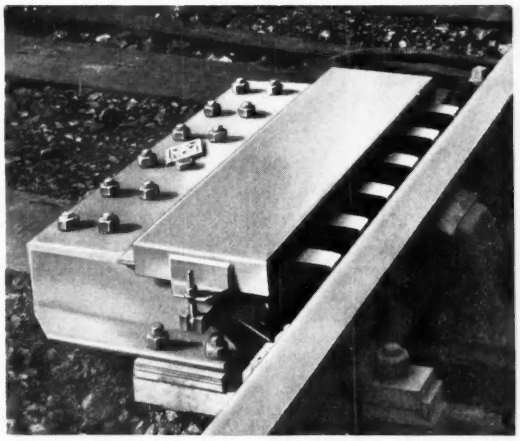

**Fig. 64.—Treadle for counting number of axles of a train passing over a section of a line.**

which shows the number of axles in section at any time. Reliable operation is obtained with speeds up to 110 m.p.h.

**Fig. 65.—Counter unit used in conjunction with the treadle shown in fig. 64.**

The connections of a track fitted with a double motor counter and an entering and leaving treadle, are shown in schematic form in fig. 66. Each motor has three pairs of poles, N and S being permanent magnets which maintain the armature in the normal position. To rotate the armature of motor 1 in a clockwise direction, coils of the poles are energized in the order aa, bb ; and to rotate anti-clockwise bb, aa. Two wires for counting and one common wire are taken to each treadle and an additional wire is taken to the entering treadle for closed circuit protection.

Considering a wheel passing over the entering treadle from left to right, the depression of C contact, which represents contacts on springs 1, 2, 3 and 4, will complete a circuit for current to flow through coils aa. The closing of contact D which comprises contacts on 3, 4, 5 and 6 springs, will similarly cause current to flow through coils bb.

### HIGH FREQUENCY INSTRUMENTS.

Rectifier instruments have been improved again in range and performance so that they can now be made for the measurement of voltage up to frequencies of over a megacycle. Ammeters (fig. 67) give readings on even higher frequencies, of the order of 10 megacycles, by the use of current transformers specially designed to give a meter calibration substantially independent of frequency within this range. In radio transmitters currents of several amperes at high radio frequencies can be measured, a robust rectifier instrument giving advantages in scale, shape, overload capacity, etc.

New high frequency equipment has been developed also for the quick measurement of inductance, capacity and loss factors of coils. These instruments are known as the L-meter, C-meter, and Q-meter respectively. The L-meter is shown at fig. 68. They consist of portable equipment of standard metal-box construction containing variable frequency oscillator,

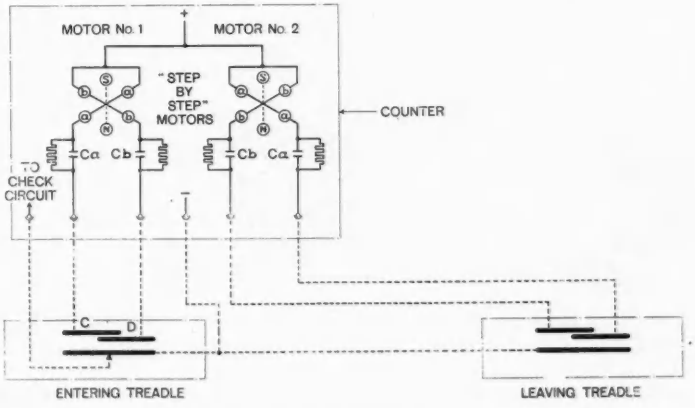


**Fig. 66.—Circuit diagram of axle counting equipment.**

detector and measuring circuit. This equipment is operated from A.C. mains and is direct reading. It has widespread application for the testing of radio components and circuits.

### CONTACT AMMETER.

A contact ammeter with an exceptionally high torque has been developed especially for use on Post

Office charging equipment. The instrument has a scale about 5½ins. long and may be fitted with one contact to make on rising or falling current, or with two contacts to make in either direction. It should be noted that the contacts of these instruments have to break as well as to make circuit. For this reason, the duty on the contacts is more severe than on relay contacts, the trip-circuits of which are broken by external means. The contact-ammeter is provided

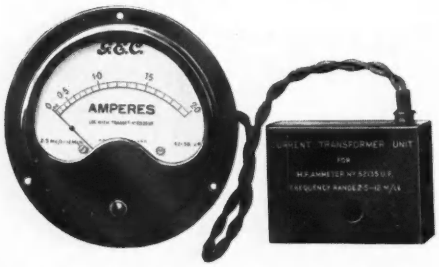


**Fig. 67.—High frequence ammeter with current transformer.**

with a dust-tight cover which is easily removable for adjustment purposes.

### VACUUM THERMO-JUNCTIONS.

Vacuum thermo-junctions, fig. 69, for use with suitable indicators are now made throughout at Salford Works. The thermo-couples in these A.C./D.C. converters are insulated from the heaters and will develop 0·006v. across a 3 ohm external resistance at rated current. The range of currents is from 0·025 amp. to 0·25 amp. and the heaters will withstand currents of nearly 175 per cent. of rating

**Fig. 68.—High frequency equipment for the measurement of inductance coils.**

instantaneously and nearly 150 per cent. of rating for a minute. The frequency errors of the 100 milliamp type, for example, relative to calibration at 50 cycles per sec., are about 6 per cent. and 12 per cent. at 13 megacycles and 75 megacycles respectively.

### MINIATURE VALVE-VOLTMETER.

A compact valve-voltmeter, fig. 70, measuring only 7¼ins. by 5¾ins. by 4⅝ins. has been designed with a self-contained battery. The instrument has three ranges, namely, 5, 25 and 100 volts, and the input impedance is 15 micro-micro-farads shunt capacitance and half a megohm shunt resistance. The voltmeter may be used for frequencies from 30 cycles per sec. to 10 megacycles and its accuracy is ± 3 per cent. on the 5 volt range and ±2 per cent. on the 25 and 100 volt ranges. A diode circuit is used, thus rendering the instrument substantially independent of valve characteristics.

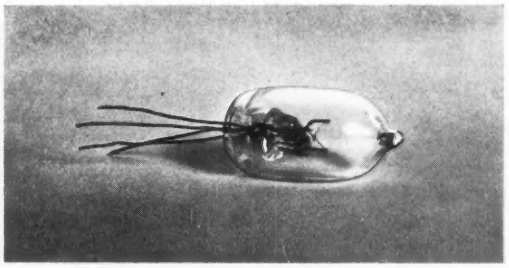

**Fig. 69.—Vacuum thermo-junction.**

### THREE-PHASE FOUR-WIRE THREE-ELEMENT METERS, TYPE "JT4."

A new three-phase four-wire three-element meter of novel construction is shown in fig. 71. Both the case and the frame on which the three driving elements are mounted are made of pressed steel. The frame is in two parts, each of channel section,

**Fig. 70.—Valve-voltmeter with self-contained battery.**

and is of very rigid construction in spite of its light weight. The front half of the frame carries the rotor consisting of a vertical spindle with three discs mounted thereon. The rotor is supported on a spring seated bottom jewel. The pivot and jewel may be removed as a unit and if necessary replaced in a few seconds. No adjustment of the rotor position is necessary after this exchange nor is recalibration called for. The counting train gears with a worm on the top of the rotor spindle and this also can be removed and replaced in a few seconds.

The counter is correctly registered with the worm and is held by a sliding bolt provided with a locking device. Two brake magnets embrace the two lower brake discs and each is independently adjustable by a micrometer screw. The low load, inductive load and balance adjustments are easily accessible and clearly marked so that calibration is very simple. The front half of the frame has six tongued extensions which fit into six slits in the rear half, thus ensuring accurate alignment. Four screws hold the two frame members together in a box-like structure. The shunt and series elements are secured on the rear half of the frame and are exposed on removal of the front half. The meter has been designed with a view to providing easy access to all parts, convenient adjustments and rapid dismantling and re-assembly. The performance of the meter is practically independent of phase rotation and the voltage and frequency variations met with in practice have no effect on the accuracy. It is possible to calibrate it on a single phase circuit and check up on a three phase circuit without having to make re-adjustments. The complete meter weighs 11½ lbs.

**DUAL-COIN TWO-PART TARIFF PRE-PAYMENT METER, WITH VARIABLE RENTAL COLLECTOR, TYPE "J.P.M.V."**

A single-phase, dual-coin two-part tariff pre-payment meter, having a device whereby a fixed charge or rental can be collected in addition to the charge for current consumed, is shown in fig. 72. These illustrations are of a meter in a moulded bakelite case.

The metering element consists of a single phase meter, type "J," which is already well known. The coin-freed mechanism is constructed to operate with shillings and pennies, either of which can be inserted. A coin register shows the total value of the coins inserted in pounds, shillings and pence, and reads up to £20, after which it re-commences from zero. A credit and debit indicator shows credit up to 5/– and debit up to 15/–. The debit portion of the scale is coloured red. The price per kWh charged to the consumer can be changed readily by means of a small removable gear compound held in position by a latch in the left hand bottom corner of the prepayment mechanism. This gear compound can be exchanged in a few seconds and is self locating so that no skill is required in order to change the price per unit.

A novel and simple device is provided for varying the fixed weekly charge or rental. A scale marked "weekly rental" and scaled from 0 to 3/– has a pointer which may be set to any intermediate position from outside the case by inserting a key through an opening which may be sealed. This device is in the form of a readily detachable unit which is secured by two screws to the prepayment mechanism. It is accurately located in position by two dowel pins and may be attached or removed from the prepayment mechanism in less than one minute. By means of this attachment the consumer may be debited with a fixed charge of any sum from 0 to 3/– per week in addition to the charge for current consumed. The fixed charge is registered by means of a small synchronous motor which runs continuously and drives through intermediate gearing on to the differential of the prepayment mechanism supplementing the registration of the meter.

The meter functions in the following manner :— On insertion of a coin or coins the pointer of the credit indicator moves from zero to that part of the scale marked "shillings unused," and at the same time a switch is closed, permitting the consumer to take a supply of the current. The pointer travels back to zero at a rate depending upon the amount of current used and the value of the weekly rental charge. On reaching zero, the switch opens and the supply is interrupted. If a coin is not immediately inserted, the pointer will travel on to that part of the scale marked "shillings arrears," and if left in this condition, will continue to register until 15/– arrears is reached. If the meter is set to collect 1/– per week this would take 15 weeks. Before the consumer can obtain a further supply of current, all arrears must be paid off by the insertion of coins after which any additional coins inserted will reclose the switch and put the consumer in credit.

**Fig. 71.—New 3-phase, 4-wire, 3-element meter.**

The illustration, fig. 72, shows a meter having a rental collector capable of collecting up to 3/– per week. If desired, however, larger amounts than this can be collected by a simple modification in the mechanism.

DIRECT CURRENT FIXED CHARGE COLLECTOR.

The "Fixed Charge" collector shown in fig. 73 consists of a prepayment mechanism arranged to operate with shilling coins. It is intended for use where a fixed weekly sum is collected from a consumer of electricity, such as the instalments on

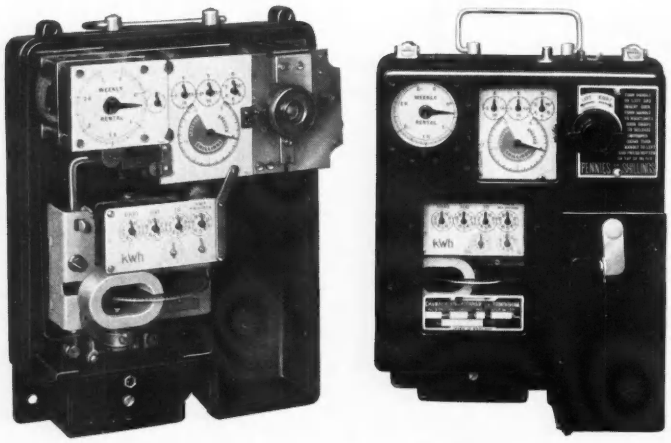

**Fig. 72.—Dual coin, two part tariff prepayment meter with variable rent collector.**

assisted wiring, the hire of an electric cooker, the hire purchase of electrical apparatus or the like. It can also be used in conjunction with a meter for collecting the fixed charge from a domestic consumer taking a supply on a two-part tariff.

The device consists of a mechanism such as is used in an ordinary prepayment meter with slight modifications and geared to a continuously running self winding electric clock instead of the usual meter. It can be set to collect any sum from 0 to 10/– per week, the desired amount being determined by a small gear compound which can be changed from one value to another in one minute.

The insertion of one shilling closes a switch and if geared for one shilling per week, the switch would remain closed for one week after which a further coin would have to be inserted. The consumer may prepay up to 5/– at any time. When the prepaid amount is used up the switch opens and the supply is cut off until further coins are inserted. If no coins are inserted arrears will be registered at a rate proportional to the amount for which the gearing is set, and until these arrears are paid off by inserting coins no further supply of current will be available.

A coin register is provided, which shows the total number of coins which have been inserted. A large coin box is fitted in the front of the meter and this can be secured by means of a padlock. The collector is fitted in a pressed steel case and can be supplied for currents up to 25 amperes at 250 volts. The clock winds approximately every half-minute and the consumption of electricity is negligible. It is fitted with a high class lever escapement which is fully jewelled.

ELECTRIC FURNACES.

An interesting furnace equipment recently completed is a 12/15 cwt. G.E.C.-Brown Boveri electric arc furnace plant (fig. 74), installed at the works of Johnson Matthey & Co., Ltd., of Brimsdown for the melting of nickel alloys. The incoming supply to the furnace is at 11,000 volts and is stepped down by a 300 kVA transformer which provides, by means of an off-load tapping switch and by the use of delta and star connections on its secondary side, a range of voltages from 45 to 105 volts. The furnace itself consists of a welded steel body lined with insulating and refractory bricks through which the carbon electrodes pass. The vertical adjustment of the electrodes is controlled hydraulically and current regulating relays automatically control the movement of the electrodes to give a constant arc current. It has been found in practice that the hydraulic method of control gives a very accurate electrode adjustment.

A range of furnaces has been made for the production of safety glass. They are arranged to carry the glass vertically from a nickel-chrome beam at the top of the furnace chamber. Glass sheets from 34ins. to 40ins. high by 25ins. to 111ins. wide can be accommodated. The ratings of the furnaces range from 60 to 95 kW and, to ensure evenness of

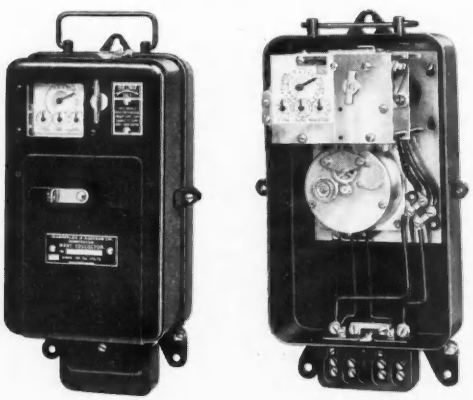

**Fig. 73.—D.C. fixed charge collector.**

control, the heating elements are mounted in vertical zones, each zone being supplied from a separate tapping on the secondary side of a transformer.

For the bright annealing of small steel and iron parts, particularly parts requiring special treatment for magnetic properties, a 40 kW hood type furnace

with two bases has been developed. A centre heater is provided in each base and the charge is accommodated in annular baskets, so that the heating is almost entirely by direct radiation. In view of the comparatively large area exposed to direct radiation the heating is extremely even. The furnace is designed for use with an atmosphere of hydrogen and nitrogen obtained from cracked ammonia.

For the continuous bright annealing of steel strip in lengths a roller hearth type of furnace has been developed and is rated at 220 kW. The internal width is 2ft. and the overall length 114ft. The furnace is suitable for operating up to temperatures of 1,000°C, and will give an output of approximately 15 cwts. per hour. A 12/1 variable speed drive is incorporated enabling the same output to be obtained when dealing with different thicknesses of strip. This furnace is also arranged to operate with an atmosphere of hydrogen and nitrogen.

Two crematorium installations are in hand each comprising a 60 kW furnace specially designed for this particular work. Complete combustion is obtained quickly by the circulation of fresh air, a recuperator of special design forming an essential part of the installation.

HEAVY COOKING EQUIPMENT.

Interesting developments have been made in the design of heavy cooking equipment and an entirely new range of equipment of this class has been produced which represents a radical departure from conventional standards of design.

The new models are made with a completely smooth exterior which in combination with the vitreous enamel finish enables them to be kept scrupulously clean.

Fig. 75.—Electric bain-marie with hot cupboard.

Two types of cooking range are available, one for general purposes in any class of kitchen and the other, which is known as the Hotel range (fig. 77), for heavy and continuous work under the severest conditions of use. Both types of ranges incorporate G.E.C. anti-drip type hotplates and a special hob which protects the internal wiring from the effects of spilt liquids, etc. In the hotel range the hob embodies a novel development. Two groups of fast boiling plates are provided but, in addition, invisible hotplates are fitted underneath the hob itself and provide additional low temperature heating surfaces for simmering purposes. The oven elements in the hotel range are totally enclosed in steam-tight steel tubes. Being completely protected in this way they are practically indestructible. Open coil radiant elements are fitted in the ovens of the standard range.

Fish fryers, grillers and hot-cupboards have been introduced

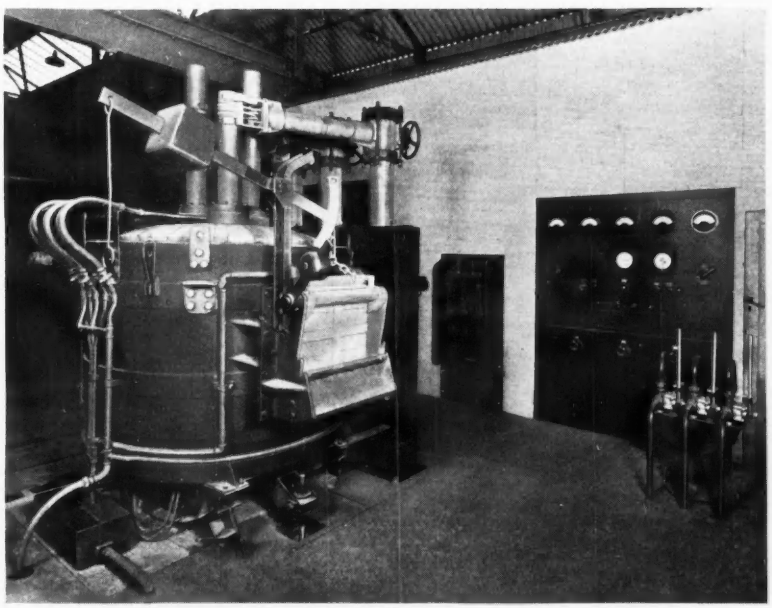

Fig. 74.—12/15 cwt. electric arc furnace installed in works of Johnson Matthey & Co., Ltd., of Brimsdown for the melting of nickel alloys.

with the same general characteristics as the ranges. The new form of grill, fig. 76, known as a solid grill, consists of a special heated plate arranged at a slight angle to the horizontal, on which the meat is placed. The fat is collected in channels mounted along the front of the grill.

During the year a number of large baking ovens of brick construction (fig. 78) have been built in co-operation with Melvin & Gillespie, Ltd., Glasgow; the heavy mass of the brickwork and its consequent great thermal capacity have enabled excellent results to be obtained.

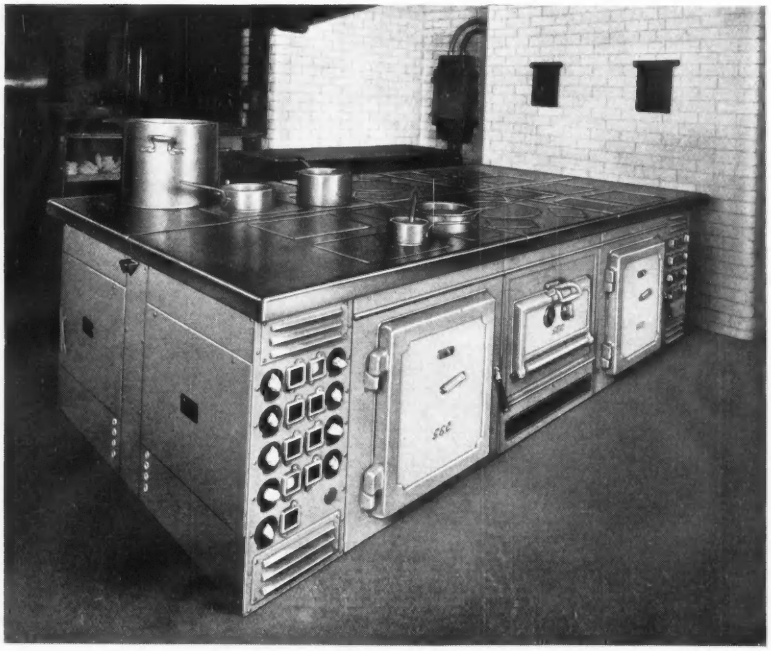

**Fig. 77.—Chef's sectional range at Magdalen College, Oxford: total loading, 100 kW.**

### DOMESTIC COOKERS.

In connection with domestic cookers, considerable progress has been made with the development of oven thermostats, which now include an "off" switch mechanism (fig. 79). The effect of this is to reduce the operating temperature to well below 32°F in the "off" position so that the thermostat will not function in the coolest kitchen. The heat numbers ranging from 0, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2 up to 14, are evenly spaced right round the dial. Thermostats of the modified pattern can be fitted in place of the oven switch in cookers for manual control.

Extensive research into vitreous enamelling problems has resulted in a special acid-resisting enamel being prepared which is now used as standard on all G.E.C. cookers. Hitherto it has only been possible to obtain satisfactory results with the mottled grey finish, but as a result of these developments, new pastel shades are available possessing the acid resisting quality.

### HOUSEHOLD APPLIANCES.

The recently developed sheathed wire heating

**Fig. 76.—Electric grill.**

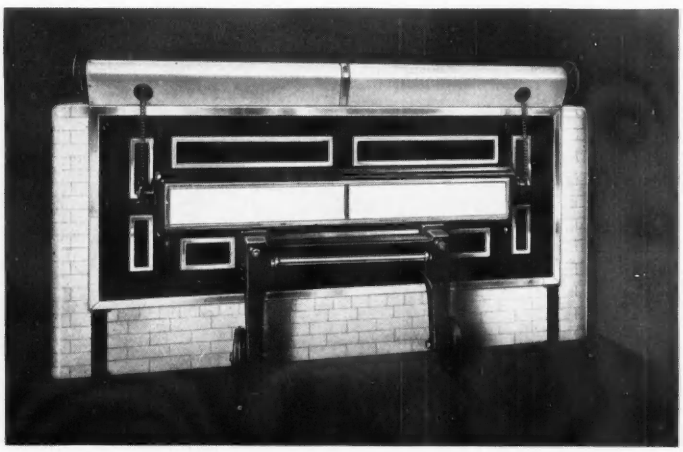

**Fig. 78.—Brick constructed electric baking oven.**

element and its application to boiling plates, immersion heaters and circulators, has been referred to in previous issues of this Journal[7]. During the past year a new range of kettles has been introduced incorporating immersion elements made on the same general lines. A bimetal operated safety device, of the connector ejecting type, is built into the head of the element to give protection in the event of accidental misuse (see fig. 80). A 3 pint kettle, fitted with this type of element, loaded to 1,500 watts will boil 3 pints of water in $7\frac{1}{2}$ minutes.

Three new electric irons have been introduced; a popular model to meet the demand for a cheap reliable iron; a streamlined model with a chromium plated finish; and a 5-lb. universal voltage iron.

Two interesting applications of moulded plastics are the new bakelite fan heater, fig. 82, and the bakelite electric fire. Both appliances have an all-insulated bakelite body.

### DAIRY STERILIZING PLANT.

The use of electrical equipment for sterilizing milking utensils has made great progress, and further experience has been obtained with the 7/20 kW electrode steam raiser developed by the G.E.C. for this and other purposes when only small quantities of steam are required. Fig. 81 shows a typical installation where one of these steam raisers is employed for sterilizing a 3-unit Combine milking plant. This plant has to be sterilized *in situ* by passing steam through the milk pipes and the glass jars in which milk is weighed and measured immediately after leaving the cow. The steam raiser also operates a lagged sterilizing chest for utensils, and provides hot water for washing up. The consumption per operation is approximately 15 units.

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**Fig. 79.—Electric cooker shown cut away to reveal oven thermostat.**

**Fig. 80.—Electric kettle fitted with renewable sheathed wire heating element.**

### RADIO SETS.

The current season's sets embody several advances from the user's point of view. Some of these are essentially features of mechanical design, such as a simple two speed tuning control which enables a wide range of tuning to be covered with a minimum of effort, and a type of edge lighting for the tuning dials which makes them exceedingly clear to read and facilitates the addition of auxiliary pointers showing the position of the auxiliary controls.

In the five and six valve superhets extremely simple and effective circuits have been developed to enable short wave reception to be carried out with a minimum increase in cost. This season there is a large number of sets in this class, as both types are made in A.C. and D.C./A.C. versions, and they have also proved very suitable for the overseas market when modified to include the medium and two short wave bands.

Two sets have been produced in which push-pull output stages are used to enable a large output power to be obtained with a minimum of distortion. One of these sets has four wavebands and one three wavebands, with a special model incorporating the overseas wavebands. In the three waveband sets a special phase reversing valve is used with a resistance coupling to a push pull triode output stage.

In the larger mains sets the variable fidelity feature of last year's sets is again incorporated.

Earlier in the season, a transportable set was developed; the design of this is such that a high level of sensitivity has been attained with a much lower level of back ground noise than is usual in these receivers.

RADIO INTERFERENCE SUPPRESSION.

The necessary apparatus has been provided at Witton Development Department for making the measurements which will be required by the regulators that will be used in the near future. A maximum figure for the disturbance has been provisionally agreed upon by the Radio Interference Committee. Practically, the whole range of motors, etc., made at Witton has now been tested with the result that details of the suppressors required by each item has been determined and tabulated.

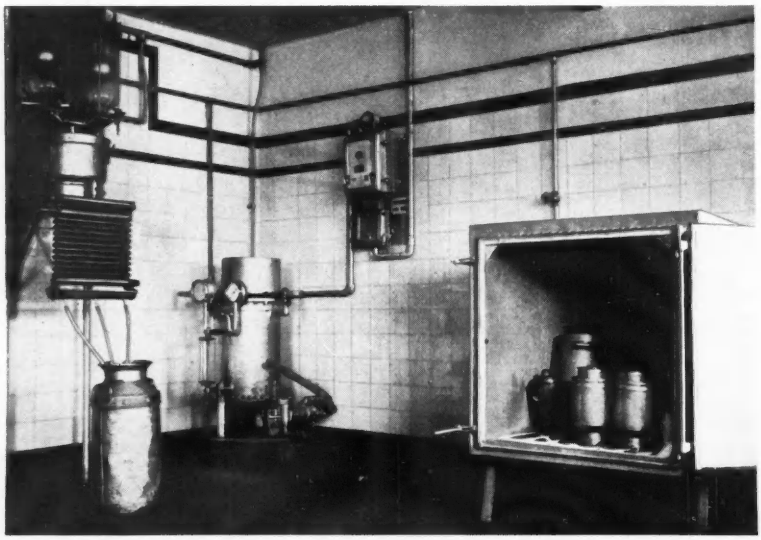

**Fig. 81.—Electric steam raising equipment for sterilizing milking plant.**

RECEIVING VALVES.

The outstanding event in connection with receiving valves has been the introduction of the so-called "International" range of valves. These valves, as well as the other valves described below, are the result of co-operation between the Research Laboratories and the M.O. Valve Works. Their characteristics, dimensions and form of capping resemble current American equivalent practice; for this reason they mark a notable departure from the previous general marketing policy of British valve manufacturers. The main reason for this innovation has been the desire to concentrate upon a single range of valves to meet the demands of both the home and overseas markets. Since questions of servicing and the stocking of replacement valves have influenced overseas users in favour of American practice, and since the trend of modern radio-set development at home is towards the use of circuit methods based on valves with high reliability and characteristics of moderate slope, it has been possible to reconcile the demands of the two markets by the introduction of the present range, and at the same time secure the manufacturing advantages attending an increased numerical demand.

Features of the new range are: a heater rating for the majority of types of 6·3V 0·3A, making their use equally practicable in A.C. (parallel running) and universal (series running) receivers, and the employment of the American "Octal" base. Fig 84 shows the general design of this base. It is fitted with solid pins spaced on the circumference of a circle and a central spigot of greater length than the pins, bearing a key which, registering with a corresponding keyway on the base, secures the correct orientation when inserting a valve, without the tedious searching which sometimes accompanies attempts at the

**Fig. 82.—Electric fan heater in bakelite case.**

replacement of valves with non-registering systems.

Certain valves in the new range deserve particular mention.

The X65 valve is a frequency changer triode-hexode based on a 6·3V. 0·3A cathode system (1·9 watts). This is the lowest cathode rating for a valve of this type that has so far been produced by any valve maker, and offers two particular advantages; in the first place the design is such as to secure a very satisfactory performance at short wavelengths, since by reason of the very low order of positive grid current encountered in this region the effective gain is little less than that obtainable in the medium and long-wave ranges; in the second place, its heater rating makes it available for use in universal receivers.

It is noteworthy that this valve represents a step in advance of American practice, where no equivalent type has so far appeared in a final form.

Among output valves the KT66 and KT32, rated at 6·3V., 1·27A., and 26V., 0·3A., respectively, are of interest as being the first examples of output tetrode valves in which high output efficiency is obtained by incorporating in the design the method of grid alignment—a feature of valve design based on the principles of electron optics.

**Fig. 83.—Television receiver for plugging into existing radio receiver.**

The range includes further novelties in the shape of the D63—a double diode valve affording increased flexibility of circuit design by reason of its two independent cathodes, and the tuning indicator type Y63, to which the name of "Tuneray" has been given.

This latter is of unusual appearance; it combines in a single bulb an orthodox thermionic triode with a miniature cathode ray tube of simplified design. Resonance is indicated by movement of a sector of shadow in the field of glow, and the indicator has the advantage that its functioning is purely auxiliary: thus if failure of the indicator should occur the tuning indication alone is lost, no other fault being caused in the performance of the set, a feature of some practical importance.

**Fig. 84.—One of the "International" range of valves fitted with the American "Octal" base.**

The construction of many existing output pentode valves has been revised and constructions of tetrode form, bearing the general type reference "KT" as distinct from "PT" or "N" have appeared in substitution for the previously existing types.

The "acorn" high frequency valve constructional technique has been extended and now provides an H.F. Pentode, type ZA1, capable of satisfactory amplification at frequencies as high as 300 Mc/sec., and in the range of battery valves type KT21 is worthy of mention as, with its filament rating of 2 volts, 0·3 amp. it affords the most efficient combination of sensitivity and output that has yet been attained in a battery valve.

The experience of 1937 has shown that, in service in the field, the performance of the valves introduced for special television use—MSP41, D42, A748, U16, U17 and the like—has been very satisfactory. Attention has recently been devoted to the provision of an intermediate frequency amplifier valve combining high working slope with minimum input inter-electrode capacity, and the Z41 is the result, affording a working slope of 7·5 mA/V with an input capacity as low as 14 $\mu\mu$F.

### TRANSMITTING VALVES.

A range of pentode transmitting valves has been introduced with anode dissipation ratings of 25, 40, 75, 250 and 750 watts. The two larger valves incorporate the air cooled anode construction and all types are suitable for suppressor grid modulation. These valves have been designed to operate at short wavelengths.

A new water cooled modulator valve, type CAM6, has an anode dissipation of 30 kW and an operating anode voltage of 15 kV. In this type forced air cooling of the filament leads replaces the

more usual water cooling. A new type of valve, similar to the CAT14, but having an emission of 150 amperes 90% saturated and an operating anode voltage of 20 kV has also been produced.

### ULTRA-SHORT WAVE TRANSMITTING VALVES.

Particular attention has been devoted to improving the life and stability in operation of megnetrons. The life now obtainable compares favourably with that of other types of ultra-short wave valves. Development in the direction of higher output powers is typified by a radiation-cooled valve now being standardized which gives an output of 150 watts at 90 cm. and 100 watts at 70 cm. wavelength. The use of new materials in the construction of this valve has led to exceptionally small overall dimensions for its power rating and to economical operation.

The use of forced air cooling for valves of anode dissipations up to a few kilowatts has been extended. This principle is of great value for ultra-short wave valves and a new type, the E773, giving an output of 300 watts at 2·5 metres with an efficiency of 50 per cent has been produced. Its minimum wavelength is 1·2 metres. An ultra-short wave glass triode has also been developed. This valve, the DET12 gives a useful output of 8 watts at 90 cms. and reaches long wave efficiencies at 3 metres, where the output is 60 watts.

### FRACTIONAL HORSE POWER MOTORS AND THEIR APPLICATIONS.

An induction motor working on the shaded pole principle has been developed for use with hair drying equipment of the "Hood" type. This machine is free from radio interference and requires no special starting gear. It is rated at 1/40 h.p. at 1,200 r.p.m.

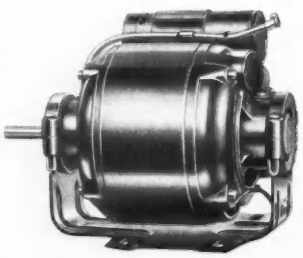

**Fig. 85.—1/6th h.p. single phase capacitor start induction motor for refrigerators.**

The special features of the motor are its silent running and the lengthy period through which it will operate without additional lubrication. In order to secure these features, the bearings are made of oil-retaining metal and a thrust washer is added to take charge of the added load, due to the inclination at which the motor has to operate. The motor will run in temperatures up to 140°F.

A new domestic refrigerator motor is of the single phase capacitor start induction type; its rating is 1/6 h.p. at 1,440 r.p.m. Precautions have been taken in the design and manufacture of this machine to ensure very quiet operation; to this end it is mounted on resilient bushes in a special cradle. A similar machine can be wound to give ¼ h.p. at 1,440 r.p.m. either as capacitor start or as plain split-phase which renders it suitable for ordinary industrial applications.

**Fig. 86.—Electrically operated drink mixer.**

Two new capacitor type motors have been added to the existing range. They are rated at 1/20 h.p. at 1,400 r.p.m. and 1/40 h.p. at 1,400 r.p.m. These machines are arranged to start and run with a condenser in circuit. They are suitable for applications where a starting torque of approximately full load is required and have the advantage that there is no centrifugal starting switch. They give an approximately constant speed at all loads and are free from radio interference.

A range of brush trailing type repulsion start induction motors has been introduced. The machines are particularly suitable for running up against heavy loads, since the brushes restore the surface of the commutator during the heavy starting period.

A new design of drink mixer, fig. 86, has been developed, which is supplied with stainless steel blade and mixing shaft. A totally enclosed motor is provided of smooth exterior design which prevents the accumulation of dirt. The drink mixer is supplied with a stainless steel beaker, which is found to be the most hygienic metal for use in milk bars, cocktail bars, and similar places.

### ELECTRIC FANS.

Investigation has been made upon the shape of fan blades with a view to giving the best efficiency with quiet running; as a result many improvements have been effected.

A new single phase induction type ceiling fan introduced with 60-in. blades, and named the "Madras."

A modified design of the "Malaya" ceiling fan embodies several improvements, including the provision of ball bearings; also a 6-in. coach fan has been introduced for use on passenger road vehicles.

### HOUSE SERVICE SWITCHGEAR.

Air break all-insulated switch-fuses are particularly suitable for the main control of houses or flats wired on the all-insulated system; no earth connection is necessary. Previous models of this type are widely used and the range has been increased by the addition of a D.P. switch-fuse for 50 amperes, and a splitter unit consisting of a 60 amp. D.P. switch with two 30 amp. and two 14 amp. fuses.

Models have been added to the range of cooker control switches; they are provided with a pilot lamp indicator on the front of the case in addition to the sliding semaphore indicator.

### FLAMEPROOF BATTERY CALL TELEPHONE.

A telephone equipment has been developed during the year and has been certified for use in mines, petrol stations and gas works, being intrinsically safe in an atmosphere of methane, pentane and commercial coal gas. An interesting feature is that the equipment can be operated with up to 24 lines in parallel. The sounding device is a horn which gives a most penetrating note.

### A.C. AND D.C. IRONCLAD BELLS.

Several improvements have been made to the high voltage A.C. and D.C. ironclad bells chiefly with regard to their appearance, insulation, weatherproof qualities and the method of wiring. The movement of the A.C. types is fitted with a single bobbin having a laminated core. A patented adjustable stabilising spring replaces the usual "make and break" mechanism and enables the bell to operate on the frequency of the supply, thus eliminating sparking and avoiding radio interference. A similar bell for use on low voltage A.C. transformer bell circuits is also available with the body made in bakelite.

### TORCHES.

A metal spotlight torch for use particularly in theatres and cinemas has been developed. A special switch device is incorporated in the centre of the body and enables a spot or beam of light to be projected on any desired object by rotating the metal ring in a clockwise direction. Rotation of the ring in an anti-clockwise direction prevents the light from being accidentally switched on. Although designed more particularly for theatres and cinemas the torch is useful to motorists for picking out names on signposts, etc.

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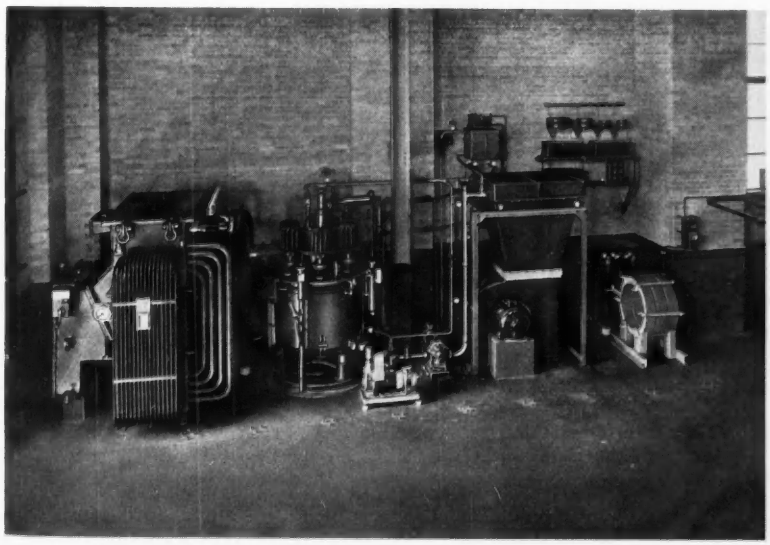
## Mercury Arc Rectifier Equipment at Brisbane.



**1,200 kW, 600 volt mercury arc rectifier and auxiliary equipment installed in the Ballow Street sub-station of Brisbane City Council Tramways Department.**

# Some Factors Governing the Design of Multi-channel Carrier Telephone Systems for Underground Cables.

By D. A. LEY, B.A.

G.E.C. Telephone Works.

THE decision of the British Post Office to reduce the tariff for long distance communication, combined with their desire to provide a "no delay" service, has necessitated a considerable increase in the number of circuits forming the trunk network.

The policy adopted in recent years of placing all main arteries of communication in underground cables, while sound, introduces the difficulty that with the present rapid expansion, it is somewhat hazardous to forecast the growth of any particular route. A cable of a certain size may be considered adequate for the next ten years, but owing to unforeseen development its capacity might be exhausted in a much shorter time.

There is a limit to the number and size of cables which can be laid along any particular route and transmission engineers have for some years been investigating the possibility of extending the scope of carrier telephony, whereby one pair of wires carries more than one channel of communication. In a normal telephone conversation, a direct current is modulated, *i.e.*, varied in amplitude, by the action of a transmitter. It hardly need be stressed that if two such currents were simultaneously passed over a line, complete overhearing would result. If, however, the second current can be separated from the first after transmission, then two effective channels will be obtained.

The voice frequencies which require to be transmitted to ensure adequate intelligibility range from 300 to 2700 cyc. This band of frequencies is therefore present in the first channel when the direct current is acted upon by a transmitter. By choosing a current of frequency sufficiently above this band to enable a filter to separate them, a second channel is obtained. Speech currents of the second conversation modulate this high-frequency current, which virtually carries the speech. It is from this fact that the term *carrier telephony* was derived.

In carrier working, as in radio broadcasting, a band of speech frequencies is superimposed on a carrier current by means of a modulator. The effect is to shift the speech band from a low frequency range to a higher frequency range, the latter depending upon the value of carrier frequency chosen. At the receiving end the reverse process occurs, a demodulator being used to restore the speech band to the low frequency range.

It will be obvious that if a second carrier be chosen, differing sufficiently in frequency from the first, a third speech band may be passed over one pair. The practical limit to the addition of carrier currents is largely imposed by economic considerations.

On open-wire lines, carrier telephony has been in operation for several years in various parts of the world, the systems perhaps most frequently found being of the single-channel and three-channel types, which give one carrier and three carrier channels respectively over a pair, in addition to the regular voice-frequency channel.

The open-wire carrier art was applied to underground cables, but, owing to the higher losses inherent in the normal types, progress was slow. Attention became directed on the reduction of losses in cables and also on the development of a high-gain amplifier capable of amplifying many channels simultaneously without distortion. During the last few years both these problems have been solved.

The co-axial cable, wherein one conductor surrounds the other has losses much lower than those of cables of the conventional design. The negative feedback amplifier due to H. S. Black has enabled many channels to be amplified simultaneously without distortion or channel interaction and the application of these amplifiers at suitable spacings on the co-axial type of cable has enabled frequencies up to 4 megacycles per second to be transmitted economically. With such a wide transmission band available, two hundred or more channels of communication can be transmitted by carrier means.

Two such cables are employed—one for each direction of transmission—and once laid, circuit provision is made by adding terminal equipment. For reasons which need not be discussed here the lowest frequency employed in co-axial cable circuits is in the neighbourhood of 60 kilocycles per second. Carrier equipment had therefore been developed for operating from 60 kilocycles upwards.

With the negative feedback amplifier available, transmission engineers turned their attention to the existing types of pair and quad cables. Measurement of the losses showed that for 40 lb. cables—a size most frequently employed—with amplifiers spaced at approximately 20 mile intervals—a frequency band up to 60 kc. could be applied.

As each channel of a multi-channel system requires a band width of 4 kilocycles for efficient transmission, it is possible to obtain 12 channels over a pair in an unloaded 40 lb. cable, utilizing the frequency range 12 to 60 kc.

Twelve-channel working is now being extensively applied on the British Post Office system, the routes for which The G.E.C. is supplying equipment being London-Cambridge, London-Leeds and London-Gloucester.

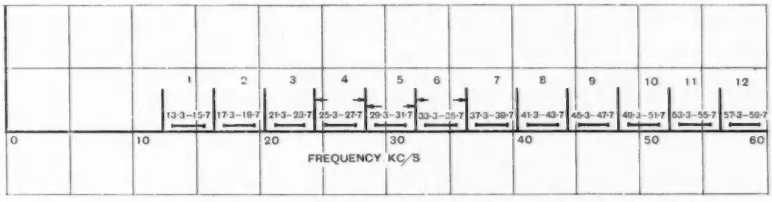



**Fig. 1.—Allocation of frequency bands to twelve channels.**

In the development of a technique of 12-channel working three possible practices could be followed :—

(1) To utilize the technique evolved for the co-axial system and by the development of suitable apparatus to apply it to the range 12 to 60 kc.

(2) To extend the technique of the aerial line carrier system. This would introduce difficulties at the higher frequencies.

(3) To adopt a method of double modulation.

For reasons which it is the purpose of this paper to explain, double modulation was adopted.

Before proceeding with the explanation, it may be advisable to consider the results of modulating a carrier frequency with a speech band. It is well known that any complicated waveform, such as that of speech currents, can be resolved into a number of sine waves of various frequencies.

When a carrier frequency *fc* is modulated by a lower frequency *fm*, the resulting wave form can be resolved into three frequencies, *viz* : *fc*, *fc* + *fm* and *fc* — *fm*, the two latter being referred to as upper and lower sidebands respectively.

Consider now a carrier, of say 10,000 cyc. modulated by a speech band which has been restricted by filters to 300—2700 cyc. The sidebands produced will extend from 7300 cyc. to 9700 cyc. and from 10,300 cyc. to 12,700 cyc. Each sideband contains the full quota of speech frequencies and it is therefore necessary to transmit only one, a filter being used to remove either the upper or the lower sideband. In modern practice the carrier itself also is suppressed; this is the optimum condition since then only the useful power of the sideband conveying the message is transmitted. The suppression of the carrier frequency means that the basic condition from which the term "carrier" was derived no longer obtains, but the fact permits a clearer understanding of the real purpose of modulation, which is to shift the speech frequencies of each channel into different positions in the frequency spectrum.

Each channel is separated from the others by filters which pass the appropriate band and reject all others, and the successful operation of multi-channel carrier telephony depends largely on the design of efficient filters.

It will be appreciated that the function of an efficient filter is to pass one band of frequencies and to reject others. In practice, filters will pass frequencies outside the pass range, and the level at which these unwanted frequencies pass through the filter is known as its attenuation in the stop range. A filter in one channel will thus accept frequencies from another, giving rise to interference, or crosstalk. The crosstalk level is given by the attenuation value of the filter at the unwanted frequency.

### Single Modulation.

In single modulation, as used on single and three-channel systems, a speech band modulates a carrier frequency to produce upper and lower sidebands, of which one is selected for transmission. Before applying this method to a twelve-channel system, it is necessary to consider the frequency range in which the sidebands lie. Allowing a speech band of 2·4 kc (300—2,700 cyc.) per channel, and a margin for the filters to rise to the requisite degree

of attentuation, it will be found that 4 kc per channel in the frequency spectrum is about the minimum that can be allocated. Since each of the twelve channels occupies a 4 kc band, the total band width required is 48 kc, and its position in the frequency spectrum, as already explained, is from 12 kc to 60 kc.

A set of filters is thus required, each approximately 4 kc in band width to cover this range. The allocation of the bands is shown in fig. 1.

The difficulties involved in designing such a set of filters will be made apparent by reference to the design of one particular filter. The circuit diagram and performance are shown in fig. 2, the filter having been selected as operating for a 4 kc band over the range 50—54 kc. It is thus in one of the higher-frequency channels, and correspondingly one of the more difficult filters to make up, but not quite the most difficult.

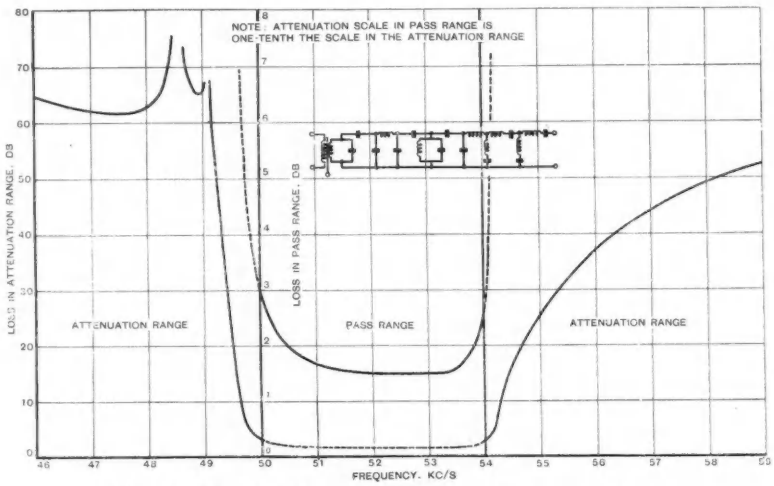

NOTE: ATTENUATION SCALE IN PASS RANGE IS ONE-TENTH THE SCALE IN THE ATTENUATION RANGE
LOSS IN ATTENUATION RANGE: DB
LOSS IN PASS RANGE: DB
ATTENUATION RANGE
PASS RANGE
ATTENUATION RANGE
FREQUENCY: KC/S

**Fig. 2.—Circuit diagram and performance curves for a filter operating over a range of 50-54 kilocycles per second.**

The following features of the filter should be noted :—

(*a*) It employs coils whose loss-factor (loss-factor = total resistance of coil/reactance of coil) is about 0·003.

(*b*) It transmits the sideband 50·3 to 52·7 kc produced by a speech band 0·3 to 2·7 kc and a 50·0 kc carrier, and attenuates the unwanted sideband extending over the range 49·7 to 47·3 kc.

(*c*) It attenuates all frequencies below 49·15 kc by at least 60 db, which means that any frequency below 49·15 kc emanating from this channel will produce interference (or crosstalk) in other channels at a level of lower than 60 db with respect to the transmitted sidebands. Conversely, at the receiving end, all frequencies below 49·15 kc entering this channel will be attenuated by at least 60 db, giving crosstalk at least 60 db down.

(*d*) For economy in design no attempt has been made to make the attenuation above 54 kc rise as steeply as on the lower side of the filter. This takes advantage of the presence of a low-pass filter in the input to the transmitter and a similar filter in the output of the receiver, which attenuate the interfering frequencies that would otherwise pass as a result of the apparent lack of suppression in the band filter. By way of example, suppose the frequency 55 kc enter this channel, it will be demodulated with 50 kc, giving 5 kc, which can easily be suppressed in the voice-frequency part of the system.

(*e*) By employment of the particular circuit designs shown in fig. 2 and also by the choice of a suitable characteristic impedance for the filter, all the coils can be chosen to have inductance values lying between, say, 5 and 15 mH, which values at this frequency enable them to be wound to a reasonable degree of accuracy, and to be designed to possess a self-capacity low enough for successful working in this type of filter. It is important to note here that low-value inductance coils possess insufficient turns to enable them to be adjusted to the required degree of accuracy, and that large value inductances are seriously affected by self-capacity.

(*f*) The pass range characteristics have been redrawn in figs. 3a, b and c. The first shows the performance when the filter is made with accurately adjusted components. It is found in practice, however, that exact components in filters employed at carrier frequencies tend

to be too costly to warrant their being called for in production, and it is therefore necessary to consider the effect of tolerances on this filter.

The curve of fig. 3a shows an amplitude distortion of 0·73 db over the range 50·3 to 52·7 kc, giving, for the transmitting plus receiving filters, a distortion over the speech range of approximately 1·5 db.

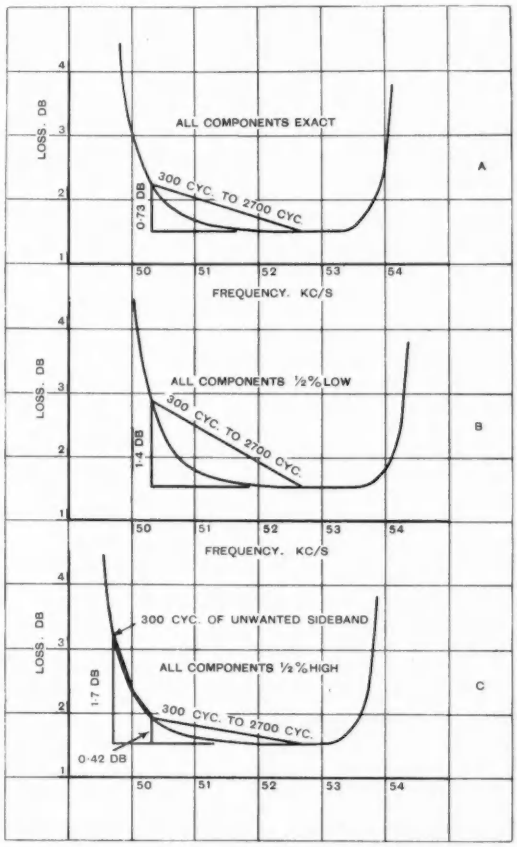



**Fig. 3.—Effect of tolerances in filter components.**

Now suppose all components are $\frac{1}{2}$ per cent. low in value. The resulting filter characteristic is shown in fig. 3b, where it will be seen that the amplitude distortion has increased to 1·4 db per filter, or 2·8 db for both filters.

Fig. 3c shows the result of all components being $\frac{1}{2}$ per cent. high in value. It would appear at first sight that the distortion is now only 0·4 db per filter but attention must now be paid to the unwanted sideband (47·3 to 49·7 kc) which is tending to come into the pass range of the filter.

A frequency of 300 p.p.s., when modulated with the 50 kc carrier, will be giving through this filter a frequency of 50·3 kc which is 0·4 db down, and also a frequency of 49·7 kc which is 1·7 db down. These two differ by 1·3 db or by 2·6 db for two filters. On demodulation with 50 kc both these frequencies will give 300 cyc., the two frequencies adding or subtracting according to their phase relationships.

In fig. 4 are two curves showing the effect of combining these two resulting frequencies, the one frequency being of lower level than the other, in addition to differing in phase. Curve *A* shows the resultant loss if the two frequencies are 180° out of phase, and curve *B* the gain if they are in phase, all other combinations lying between these two limiting curves. For a difference in level of 2·6 db for the two frequencies, anything from a 3·45 db loss to a 1·9 db gain can be obtained. Adding on the initial 0·8 db level of the original 50·3 kc (0·4 db for each filter), it will be seen that any value from —4·25 to + 1·1 db might result from the demodulation of 50·3 kc and 49·7 kc with 50 kc.

Going back to curve 3a and applying the same argument as above, it will be found that the unwanted sideband gives a variation from —1·4 to —0·1 db to the 0·3 kc.

These results are represented as overall loss (or gain) frequency curves for the speech band in fig. 5. It should be mentioned that the phase relation of the two sidebands, the wanted and the unwanted, is hardly controllable, as it depends on the type of transmission line being used, the length of the line and the number of intermediate amplifiers, the frequencies of the sidebands, the number of line equalizers, etc.

To summarize, with coils of loss-factor 0·003, and with a single modulation system, a quality curve varying between + 1·1 db and —4·25 db is to be expected when using filters giving a separation between channels of 60 db.

The decision taken by The G.E.C. was to produce

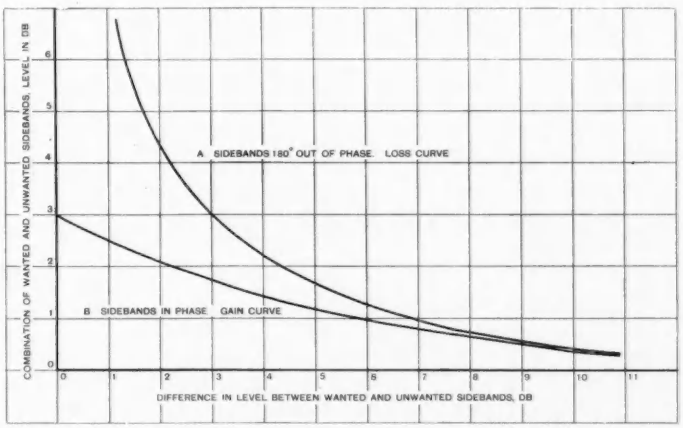

COMBINATION OF WANTED AND UNWANTED SIDEBANDS, LEVEL IN DB
A SIDEBANDS 180° OUT OF PHASE. LOSS CURVE
B SIDEBANDS IN PHASE. GAIN CURVE
DIFFERENCE IN LEVEL BETWEEN WANTED AND UNWANTED SIDEBANDS, DB

**Fig. 4.—Curves showing the effect of combining two resulting frequencies. Curve A shows resultant loss with the two frequencies 180° out of phase, and curve B the gain if they are in phase.**

a twelve-channel system having an overall speech-frequency response within 2 db, and an inter-channel crosstalk of better than 55 db (subsequently increased to 70 db). At that time the filter inductance coils available had a loss-factor of 0·008 at 50 kc, which, when translated into filter performance, means a

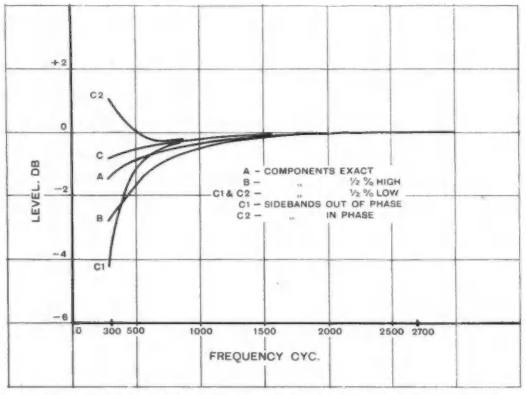



**Fig. 5.—Overall loss (or gain) frequency curves.**

variation over the pass range of worse than 0·008/0·003 (—2·67) times that shown in fig. 2, since the loss in the pass range of a filter is roughly proportional to the loss-factor of its components. Thus instead of variations from —4·25 to —1·1 db, values more like —8 db to —2 db for the 300 cyc. frequency would be found.

Having set the limits at 2 db, the method of single modulation described above will be seen to be almost impossible of application, unless channel equalisers are applied to each channel individually, to correct for the irregularities in the gain-frequency curves.

Objections to single modulation can be summarized as follows:—

(*a*) The band width is narrow in comparison with the frequency at which filters are required to operate, *e.g.*, a ratio of 4 to 50 kc.

(*b*) The filter does not rise steeply to give the required degree of suppression of the unwanted sideband.

*Double Modulation.*

Fortunately these drawbacks are not nearly so severe at lower frequencies and if the necessary selectivity can be obtained at low frequencies before the bands are allotted their final place in the frequency spectrum, then greater stability will result. This selectivity at low frequencies is made possible by the use of double modulation.

To illustrate the advantage of operating filters at low frequencies the following particulars are given.

If a filter be designed to operate at 5 kc, it will give a performance ten times better than a filter of equal band width designed for 50 kc.

For example, the loss in the centre of the pass range of a single section of the simplest type of band filter is given by

$$17{\cdot}36\ d\ \frac{f_m}{f_1 - f_2} \text{ decibels}$$

where $d$ = loss-factor of the coils,

$f_m$ = mid-frequency of the pass range of the filter.

and $f_1$ & $f_2$ = cut-off frequencies of the filter. If the bands are kept equal in width, and if $d$ is kept approximately the same (it varies from 0·005 to 0·003 at low frequencies) then the loss at the mid-frequency is directly proportional to $f_m$. That is, whereas the loss at 52 kc was 1·5 db for the filter shown in fig. 2, it can be reduced to 0·15 db for a similar filter with a mid-frequency of 5·2 kc. The variation over the pass range will be reduced correspondingly, although not quite in the ratio of 10 : 1.

The actual performance and circuit diagram of a filter working at low frequencies is given in fig. 6. The filter has been designed to pass a sideband 6·3 to 8·7 kc produced by a speech band 0·3 to 2·7 kc

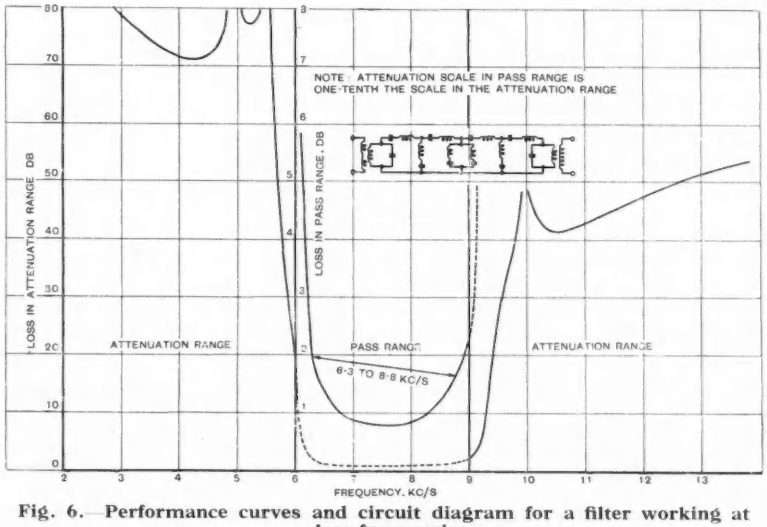

NOTE: ATTENUATION SCALE IN PASS RANGE IS ONE-TENTH THE SCALE IN THE ATTENUATION RANGE
LOSS IN ATTENUATION RANGE. DB
LOSS IN PASS RANGE. DB
ATTENUATION RANGE
PASS RANGE
6·3 TO 8·8 KC/S
ATTENUATION RANGE
FREQUENCY. KC/S

**Fig. 6.—Performance curves and circuit diagram for a filter working at low frequencies.**

and a carrier frequency of 6·0 kc. The following features of this filter should be noted:—

(1) It is narrower in band width and possesses more sections than the filter previously referred to, giving an unfavourable comparison with the latter.

(2) The filter characteristic includes the

additional losses due to the input and output transformers which have been incorporated in the filter circuit.

(3) It employs coils of loss-factor similar to those employed in single-channel or three-channel carrier systems.

(4) Components are designed to an accuracy which corresponds to a frequency shift of 30 cyc. at 6 kc compared with 250 cyc. at 50 kc. It is thus nearly ten times as stable as the filter of fig. 2.

(5) A frequency drift of 30 cyc. corresponds to a 0·5 db increase in attentuation in the very worst case (at 6·3 kc).

(6) The overall variation in the pass range is 1·2 db, to which must be added 0·5 db extra in the worst case mentioned in (5). Although this appears to be excessive in view of the final performance required, it will be shown later to be satisfactory.

(7) It suppresses frequencies below 5·6 kc by more than 70 db.

(8) It suppresses 5·7 kc by about 50 db. This frequency corresponds to 300 cyc. in the unwanted sideband, which can therefore be completely neglected and will not interfere with the quality curve of the wanted sideband.

(9) It suppresses frequencies above 9·9 kc by more than 40 db, and if this be added to the 30 db supplied by the demodulator output filter, as previously described for the single modulation system, a total of 70 db is obtained in interfering frequencies above 9·9 kc.

This filter will thus be seen to give a consistent performance and to pass a sideband almost entirely free from interference by the unwanted sideband.

Such a filter can be used in the conversion of a speech band of 0·3 kc to 2·7 kc into a single sideband 6·3 to 8 kc with a maximum amplitude distortion of 1·7 db and free from all extraneous frequencies to the extent of 50 db.

12 kc separation between the two sidebands, and this enables a comparatively simple filter to be used for selecting the one band and suppressing the other. Therein lies the advantage of double modulation.

The performance of a typical filter used for selecting the required sideband after double modulation is shown in fig. 7. Although the filter curve appears to distort rather badly, the centre portion of the pass band is comparatively flat and free from distortion. In addition, no trouble will be experienced from the unwanted sideband, which has been suppressed by 70 db per filter (transmitting and receiving).

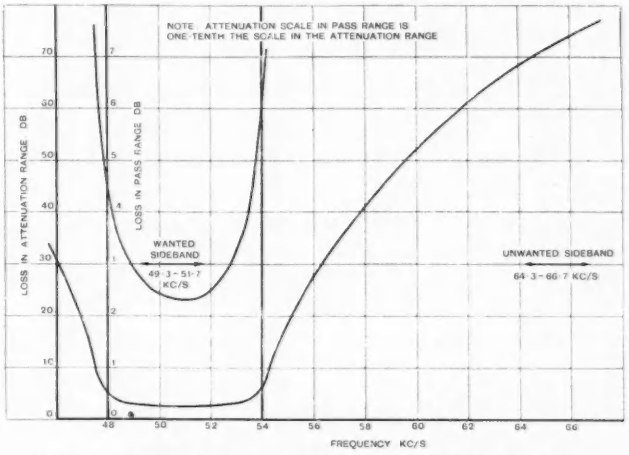

NOTE: ATTENUATION SCALE IN PASS RANGE IS ONE-TENTH THE SCALE IN THE ATTENUATION RANGE
LOSS IN ATTENUATION RANGE DB
LOSS IN PASS RANGE DB
WANTED SIDEBAND
49·3-51·7 KC/S
UNWANTED SIDEBAND
64·3-66·7 KC/S
FREQUENCY KC/S

**Fig. 7.—Performance curves of a typical filter used for selecting the required sideband after double modulation.**

Adding the effect of the two filters used in the two separate stages of modulation, it will be seen that a final sideband has been obtained, possessing very little distortion, even though normal-quality inductance coils have been used. More important still, the distortion that does occur is nearly constant in its effect on each channel and can therefore be compensated. The correction can be obtained by careful design of the frequency changers in conjunction with the filters to give the desired effect.

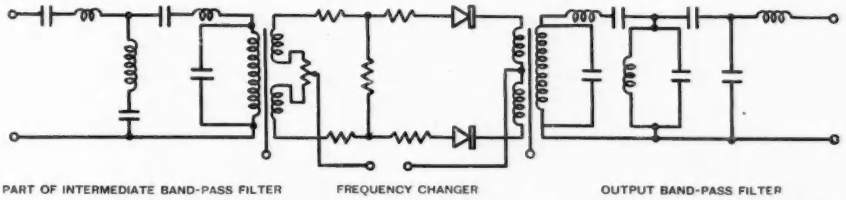



**Fig. 8.—Circuit diagram of frequency changer with its associated intermediate band-pass filter and output band filter.**

If now this band, 6·3 to 8·7 kc, be modulated with a second frequency, say 58 kc, it will produce two sidebands, 51·7 to 49·3 kc and 64·3 to 66·7 kc. If the lower sideband be selected, the other must be suppressed by at least 70 db to prevent interference in other channels. But there is now a

The principles involved will be made clearer by reference to fig. 8, which shows the circuit diagram of a second frequency changer and its associated intermediate-frequency band-pass filter and output

band filter. The use of two rectifiers in the manner shown gives a high-impedance modulating circuit.

The input impedance of the filters as seen from the rectifiers can be made to increase as the frequency departs from the mid-frequency of the filter—the impedance at mid-frequency being low compared

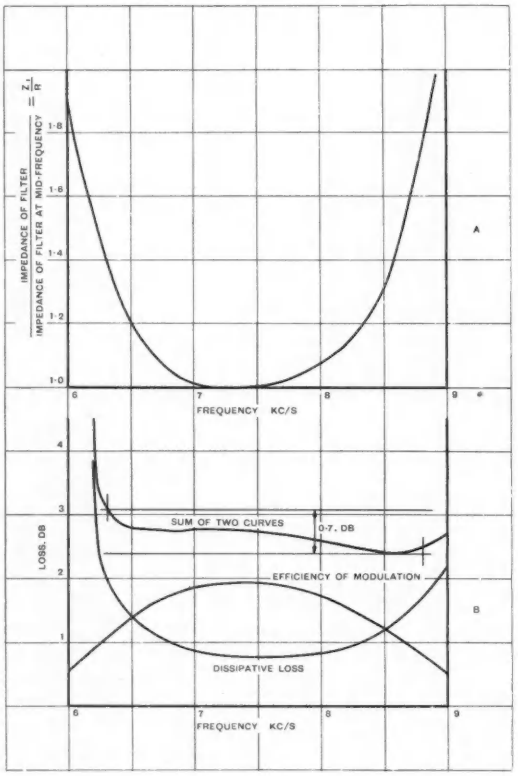



Fig. 9.

with the frequency-changing circuit. The impedance-frequency curve of the intermediate-frequency band-pass filter is shown in fig. 9A. Since the impedance of the filter is low at the mid-frequency a loss in the efficiency of modulation of the frequency-changer circuit must be expected. Again, since the filter impedance increases as the cut-off frequencies are approached, this loss will decrease. A means is thus obtained of compensating for the loss introduced by the filters, which varies in a manner opposite to that of the loss just described. By suitable choice of the controlling resistance in the frequency-changer circuit this variation in loss can be controlled and made almost to neutralize the variation given by the intermediate-frequency filter.

An illustration of the effect of combining these two variations is shown in fig. 9B, which shows the modulation loss between the intermediate band-pass filter and the frequency changer, and also the loss in the pass range of that filter. In the particular case shown the sum of these two losses gives a curve which varies by 0·7 db. Further small compensations between other terminals of the two frequency changers used in each channel gives an almost flat overall gain-frequency response curve.

Uniformity in the manufacture of the system can be obtained by using the same design of intermediate band-pass filter and frequency changers in all twelve channels, and the compensation for all channels will be identical.

To sum up, it will be seen that the double modulation scheme has the following advantages over the single modulation scheme :—

(1) It enables a better and more uniform gain-frequency response to be obtained for all channels.

(2) Variations in components have very much less effect on the overall performance of the system.

(3) It employs a large proportion of similar equipment in each channel, with consequently simplified maintenance.

Against these advantages must be placed the additional apparatus required.

# The Appraisement of Lighting.

By CLIFFORD C. PATERSON, O.B.E., D.Sc., M.Inst. C.E., M.I.E.E.,
Director of the Research Laboratories of The General Electric Co., Ltd., Wembley, England.

*This is a verbatim report of the Guthrie lecture delivered by Dr. Paterson before the Physical Society at the Imperial College of Science, on 22nd October, 1936. The Guthrie lecture is given under the auspices of the Physical Society to commemorate the memory of Professor Guthrie, the founder of the Society.*

*The lecture deals with the various techniques which have been evolved by the physicist and the engineer for the better study of the art of using light.*

## HISTORIC.

IN the archives of one of our Ancient City Guilds—the Worshipful Company of Tallow Chandlers—we have an early document of 1680 bearing upon the official appraisement of lighting—in this case the public lighting of the City of London.

It takes but a minute to read a few extracts from this very human document—an appeal to the Court of Common Council of the City of London by the Craft of the Tallow Chandlers. These Craftsmen had already for two and a half centuries enjoyed a practical monopoly of the field of artificial lighting. For tallow candles had been the recognized means of artificial lighting with hardly a rival since before the coming of the Conqueror.

The makers of tallow candles were suddenly faced with a rival luminant—or as they charmingly called it, lucidary—the oil lamp.

This is the substance of their petition :—
REASONS humbly offered to the . . . . . Lord Mayor, Alderman, and Commons of the City of London . . . . . by the Worshipful Company of Tallow Chandlers against setting up and establishing the Lamplights of any sort in this City, as varying from the antient custom.

THAT this Company have been Incorporated about 230 years . . . . . and have always assisted as well in Purse as Person to add to its Grandure, and to the support of the present Government.

That this Company, with the whole City . . . . thought themselves safe from any other invasion of their Laws, one of which is an Act of Common Council, made the 3rd of October, 1599, whereby every Householder from the first of October to the first of March in every year for ever, should cause a substantial Lanthorn and a Candle of Eight in the Pound to be hanged without their Doors.

That notwithstanding the said Act (still in force) certain unfree Men, who are not capable of serving any office in any Company, nor Office of Trust within this City . . . . have set up, and do continue in the Streets of this City . . . . . a great number of *Convex-Lamps* and other *Lucidaries*, in opposition to, and derogation of, the said Act, and to the manifest Injury of this and other Companies, in their lawful Trades.

That the setting up, and use of the said *Lamps* . . . . . will be a great Prejudice :—

First, to this Company, in taking away the Use of their lawful trade . . . . and that if the continuance of these lamps be suffered, they will hinder the making and selling of Seventeen Dozen of Candles to every Lamp set up and used in this City . . . . in every Year . . . .

And although great annual Rents, and other Considerations may be offered to this City, by the Partners of the several New Lights (and as they pretend) towards payment of the Orphans, yet nevertheless it's hoped, that not any of those New Lights will be Established for the sake of such Rents ; and at the same time, by so doing, deprive the Tallow-Chandlers, and other Trades in the Profits thereof, to a far greater value than the Profits of the Lamps can accrue unto the Orphans.

And to other Trades, as the Horners in making of Leaves for Lanthorns for burning Candles in ; Tinmen and Spinners of Cotton, whereof the Twentieth part is not nor cannot be used in Lamps, which is, and must be in Candles ; and must necessarily deprive many Hundreds of Persons (that live solely by those Trades) of their Maintenance and Livelyhood.

It is humbly hoped that the Act of *Common Council* for enlightening the Streets of this City with Candles in Lanthorns may be strictly observed, or that this Honourable Court will be pleased to make another Act, for the more strict and regular Observance of the Duty of Lighting the Streets of this City . . . with Tallow Candles in Lanthorns, which will be cheaper to the Inhabitants than any sort of Lamps."

You will notice that each householder was from the 1st of October to the 1st of March in every year *for ever* to cause a substantial Lanthorn and a candle of eight to the pound to be hanged without their doors.

There is still something to be said for the method these pioneers used for appraising their light. Being

at that age uncontaminated by the conceptions of Physics they resisted the temptation to specify *light* and insisted with touching reiteration on the two tangible things they knew—the tallow candle and the lanthorn.

This simple and commonsense principle of appraising lighting by boldly specifying the lamps which radiate the light is probably still the most widely used in common practice.

### OBJECT OF DISCOURSE.

I am apprehensive lest this talk should degenerate into a mere lecture on photometry, and an indifferent one at that. For my object is wider. It is rather to review some of the many and varied circumstances in which one characteristic or another of light must be estimated in relation to the purpose for which the light is required. Nevertheless, the measurement of light by physical or physiological means is in fact the inevitable background of my subject.

The essential motive in the inception of the Physical Society was the study of experimental physical methods. I need make no excuse this evening therefore, if I centre my discourse round various techniques which have been evolved by the Physicist and the Engineer for the better study of the art of using light. The contributions of the Physiologist are at least as important. Certain techniques can be considered as much within the sphere of one as of the other, but my point of view and terminology will, I admit, not be that of the physiologist, although I hope that nothing I say will be at variance with a sound physiological standpoint.

When I joined the National Physical Laboratory some 35 years ago with the task of evaluating and rendering as reproducible as possible the unit of luminous intensity, *i.e.*, the candle, few people thought of the value of light to the community in terms of anything but intensity. This was unfortunate, but perhaps natural, because the intensity of a source of light was the one quality which could be readily measured. Furthermore, the idea was simple enough for engineers to understand.

The measurement of brightness, of total flux, of colour, of contrasts, of the disturbing effect of unwanted light, the differences between normal eyes and such like—measurements of all these quantities has yet to come. Some of the techniques for these are still very imperfect; but realizing the importance of the effects for practical lighting, workers are now having to seek techniques for appraising even the most elusive of them.

In some of these techniques matters have been much complicated by the appearance of new lamps which yield light of the most varied colours. The appraisement of lighting effects was difficult enough when our lamps emitted approximately white light, *i.e.*, light which can be matched in its hue with that from a black body at some temperature or another. But now that so many lamps emit merely a line spectrum of some gas or vapour, our technique must no longer assume (as used to be the case) that the light emitted approximates to that of a continuous spectrum.

### LUMINOUS INTENSITY.

#### (a) Visual Techniques.

In the early years of the century our carbon filament substandard lamps had hardly been established before the operating temperatures of incandescent lamps began to climb. The Nernst lamp, then Tantalum, Osmium and Tungsten appeared—bringing with them disturbing changes in the hue of the light.

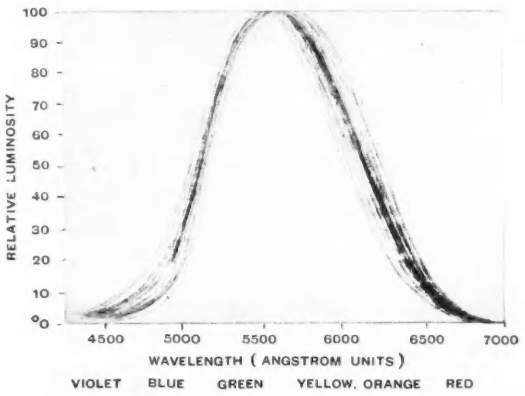



**Fig. 1.—Relative luminosity curves for 125 persons.**

It was fortunate that there were good physicists at that time who foresaw that alongside the effort to evaluate such higher temperature sources by the old methods of direct photometric comparison, a sounder and more fundamental technique must be established, based on spectrophotometric methods. The Americans undertook several very laborious investigations to determine the relative luminosity curve (fig. 1), for the average human eye—the type of curve which was, I believe, first produced by Sir William Abney.

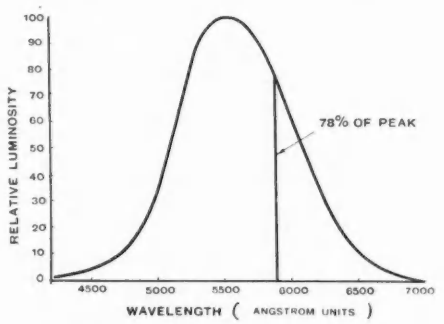



**Fig. 2.—Average relative luminosity curve adopted internationally.**

From 1912 to 1922 curves were obtained for about 250 observers and as the result (and also because the results of measurements on a group of Japanese observers showed no sensible racial disagreement, which was at one time suspected) the average curve (fig. 2) was internationally agreed. But it does not do to forget that this average diagram has as its origin the diagram, fig. 1, in which we observe the very great spread which prevails amongst normal individuals.

To allow for the deviation of individuals from the average colour sensitivity, a system, due to Ives, has been evolved for determining by a simple test, the extent of the departures from "average vision" of individual observers, so that an appropriate correction can be made to photometric observations in which a colour difference is present. This is a partially successful device only—but on the whole we are better off with than without it. Briefly, the test consists of determining for any observer the

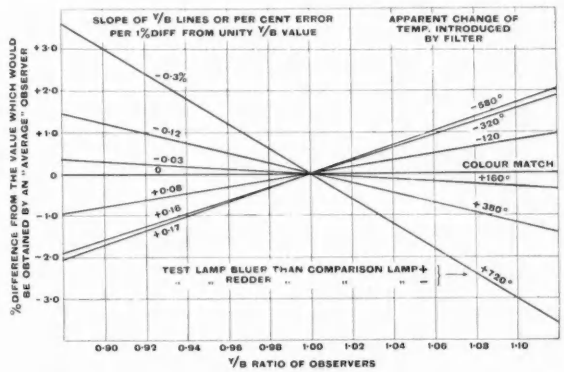



**Fig. 3.—Lines relating Y/B of observers when comparing light sources operating at different colour temperatures.**

ratio of the transmissions of specified yellow and blue filter solutions, using a Guild flicker photometer at a high field brightness, in order to ensure that the test shall apply to foveal vision. Normal observers' Yellow/Blue ratios range over a spread of about ± 15 per cent. from the mean. If these Y/B ratios are plotted against the individual observer's candle power or lumen determinations, in the presence of a colour difference, the slope of the best straight line through the observations is determined by the extent and form of the colour difference. For example, if we photometer carbon or tungsten filament light sources operating at different colour temperatures, and plot the results against the Y/B's of the observers we obtain a family of curves of different slopes (fig. 3). If we then plot the slopes of these curves against the difference in temperature of the light sources compared, we obtain a straight line relationship (fig. 4), from which we can determine the "slope" of the Y/B line for any colour temperature difference. Therefore, when photometering tungsten or carbon filament lamps, we can, if necessary, make a suitable correction to any individual observer's results provided we know the extent and direction of the colour temperature difference and the observer's Y/B ratio.

This method is only of limited application when comparing continuous radiation sources with sources emitting line or band spectra. This will be appreciated by reference to the diagrams (fig. 5), where the results of photometric comparisons between tungsten and neon, sodium and high pressure mercury sources, have been plotted against the Y/B's of the observers[1] using different forms of photometer head. In some cases we see that the "spread" from the best line through the observations is very great, and in many cases is of the same order of magnitude as the correction which the slope of the line would indicate was necessary.

It will be seen, therefore, that Ives proposal is mainly applicable when comparing light sources in which the radiation is continuous and approximates to that of a black body.

Having thus obtained, through the relative luminosity curve, a value for the luminosity at each wave-length, the spectrophotometric readings on a coloured source of light could now be interpreted in terms of the intensity value of such a source for human vision. It is obvious that the appraisement of light by this technique is easier for radiators with a continuous spectrum than for those with line spectra.

The latter cannot in fact readily be measured

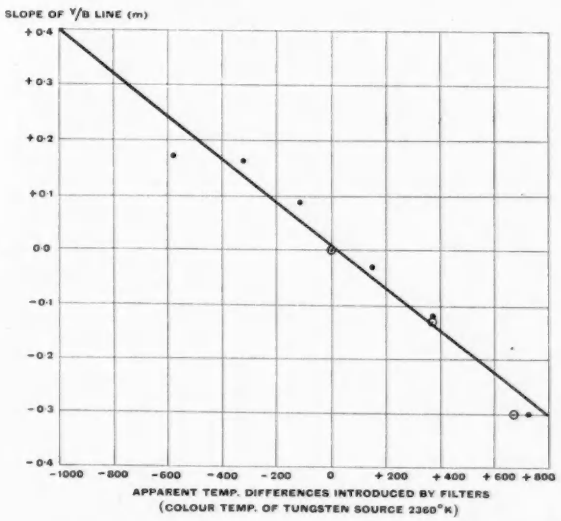



**Fig. 4.—Relation between slope of Y/B lines with colour temperature differences between the sources compared.**

spectrophotometrically. It is usual in such work to find a colour filter which, when put in front of a tungsten filament standard lamp of appropriate

1—G.E.C. Journal, vol. 5, No. 3, August 1934, p. 125.

temperature, will give a colour match (though not an energy match) with the line spectrum source to be determined. The filter is then measured spectrophotometrically for its absorption, so becoming a standard "colour converter" whose constants are known.

It may be interesting to demonstrate how closely we can approximate by filters used with filament lamps, to the colour of certain vapour lamps now in common use for public lighting.

[*To illustrate the description which follows, images of the various photometer fields mentioned were thrown on the screen.*]

You will remember how comparatively easy it is to balance a large field (6 to 8 degrees) Lummer Brodhun photometer—when there is no colour difference present—as, for instance, when comparing two tungsten filament lamps operating at the same colour temperature. We will attempt to show, by means of superposed projections, the appearance of different photometer fields when making heterochromatic comparisons.

First the 6 degree large Lummer Brodhun field. We can see, as the brightness of the adjacent fields is adjusted, how difficult it is to balance with the *full* colour difference between tungsten and high pressure mercury light. This colour difference can be *minimized* by means of a suitable blue filter in front of the tungsten source, and you will see now how much easier it is to determine the point of photometric balance as the brightness is adjusted.

For the best work a smaller field should be used in order to restrict it to foveal vision. Here is such a small 2 degree equality of brightness photometer with the full colour difference—tungsten to high pressure mercury. And next we see it with the filter in front of the tungsten source to give minimum colour difference.

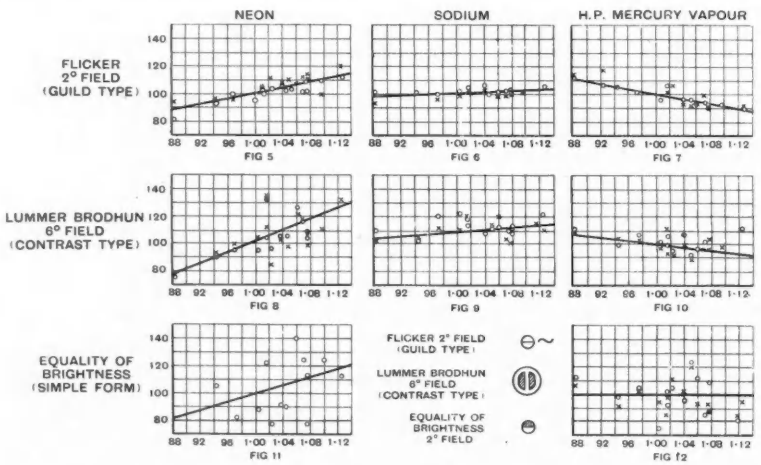



**Fig. 5.—Representative Y/B curves obtained when comparing electric discharge lamps with incandescent tungsten.**

We will now project alternately on to the same portion of the screen, a small circular (2 degrees) field from the tungsten and high pressure mercury sources, respectively. This simulates the conditions in a flicker photometer, such as the Guild photometer, except that in the latter a 25 degree steady white surround field is used to increase the comfort of balancing. The photometric balance in this case is of course indicated by the setting position at which flicker disappears. This we see is fairly easy to determine, even though the full colour difference is present as in this case. Why then use any other photometer than the flicker for heterochromatic comparisons? There is a drawback of course. The flicker photometer must be operated under carefully prescribed conditions and is very tiring to use continuously. It is unsuitable for making routine day to day measurements.

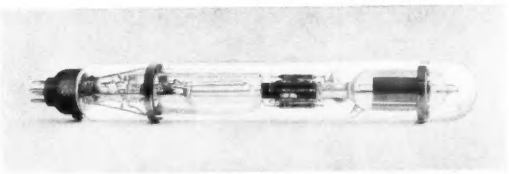


**Fig. 6.—Valve photocell unit.**

Even with carefully chosen filters and yellow and blue corrected human individuals, the measurement of the intensity of different coloured modern lamps is liable to considerable uncertainty.

So you see it is all rather artificial. We are trying to make of the human eye as accurate and reproducible a measuring instrument as we can. But when we have done all the things I have just described, I am not sure how accurate is the claim that we are basing our appraisements of light on the judgments of human vision.

**(b) Photoelectric Techniques.**

Having consented to this measure of arbitrariness our critics will hardly complain if we seek the assistance of the photoelectric cell to replace the eye, and to relieve it of the tedious and exacting discriminations which this photometric work involves.

The photocell of course has its own traps for the unwary, which are both optical and electrical in character. In the case of photocells of the Elster-Geitel type, which are still found to be most suitable for high precision measurements, the chief electrical

uncertainties are surmounted by housing the photocell complete with amplifying valve and grid leak in an evacuated glass envelope (fig. 6). By this means instability due to variable surface leakage is avoided and the highly insulated lead from photocell to valve is extremely short. This enables the unit, together with its associated components, to be

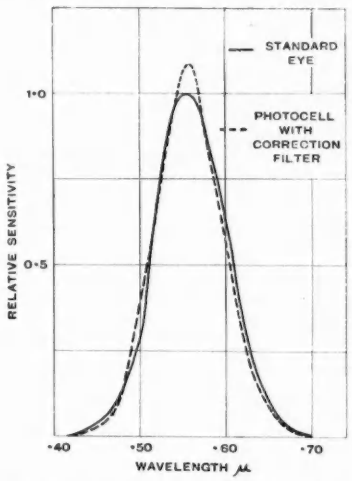



**Fig. 7.—Relative spectral sensitivity of photocell with correction filter to give "average eye" response.**

efficiently screened from external electrical disturbances.

Other causes of uncertainty in such photoelectric apparatus may arise (*a*) from the temperature coefficient of the photocell, (*b*) fatigue, and, in bad quality cells, (*c*) departure from linearity of response. Also, where it is required to make illumination measurements, errors may occur due to departure from true cosine response and of course the fidelity with which the relative luminosity curve of the cell corresponds with that of the average human eye. No cell as yet approaches sufficiently near the required distribution, but Preston at the National Physical Laboratory has studied light filters for use with a certain thin film potassium photocell and has produced the high degree of coincidence shown in fig. 7 with a loss of sensitivity of about 75 per cent. when measuring tungsten radiation and about 80 per cent. with high pressure mercury lamps. But such a loss does not matter when we can have practically as much amplification as we choose. Thus, you see by using a photocell with a carefully designed filter and a substandard lamp, we can approximate to the judgment of the limited region at the centre of the fovea of the average human eye and so obtain a consistent measure of the intensity of our coloured sources of light.

In general, the Elster-Geitel type of photocell is chosen for precision measurements, because of the higher stability available in special types, and the fact that it is a high impedance device and therefore the photoelectric current can readily be amplified. However, the selenium rectifier type of photocell is gaining popularity for industrial photometric purposes because of its simplicity. This type of cell is a low resistance device which can be connected direct to a low resistance microammeter (50–100 ohms) the indications of which will be closely proportional to the incident light. Fortunately, the spectral sensitivity of these cells (fig. 8) although departing by an appreciable amount from the "average visibility curve," is a sufficiently close approximation to enable the light output or illumination from incandescent tungsten sources, over the normal range of operating temperature, to be compared, to an accuracy of the order of 5 per cent. Colour filters have also been proposed and made for use with this class of cell so that it may be used for comparing coloured light sources. But the absorption of such filters is necessarily high if accurate correction to "average eye sensitivity" is required, so that the application is strictly limited, as amplification is not possible due to the low resistance of the cell.

Even though some may be inclined to be critical of all these artificial aids to absolute accuracy, there is no doubt about the extraordinary sensitivity obtainable by the use of the photocell in photometry. I speak of sensitivity, not of absolute accuracy, and for many purposes sensitivity is more important than absolute accuracy.

[*The lecturer then showed a photometer and control gear which employed a photocell for appraising the intensity of the light falling on it. The galvanometer was shown to give a deflection of about 3 feet for one-half per cent. change in the light falling on the cell. The apparatus incorporated one of the composite*

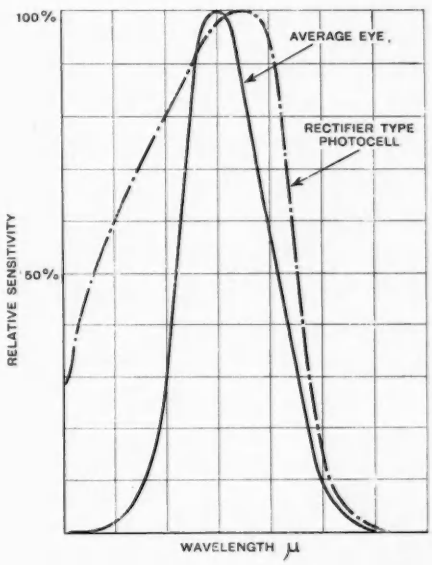



**Fig. 8.—Relative spectral sensitivity of rectifier type photocell and average eye.**

*vacuum units referred to earlier in the lecture, the electrical amplifier circuit being effectively screened. Actually, the unit in this photometer was fitted with a grid leak of approximately* $10^{-11}$ *ohms giving a maximum detectable sensitivity to light of* $10^{-9}$ *lumens. This was reduced to* $10^{-7}$ *when used with the galvanometer incorporated in the control cabinet.*]

The photoelectric photometer is an exceedingly useful technical device and a tribute to those who have brought it to such a state of refinement. But it does not concern us or assist us very much in the broader aspects of the appraisement of lighting.

There is one application which demonstrates very well the convenience of the selenium rectifier photocell in an industrial laboratory. Polar curves of lighting fittings —or may we call them lucidaries—are tedious to take and to plot. This is particularly so with many modern types of which the polar curve is not a figure of rotation, but is designed to be asymmetric, in order, for instance, to throw more light up and down a street than across it (fig. 9.). In order to define them, such lucidaries require a considerable number of polar curves taken in different planes through their vertical axes—which is all exceedingly tedious. Two solid polar curves are illustrated in fig. 10, the one from a bare lamp and the other from the same lamp plus its optical housing.

[*A device was then demonstrated in which a photocell rapidly explored and recorded the light intensity in one plane after another, enabling the work to be done expeditiously.*

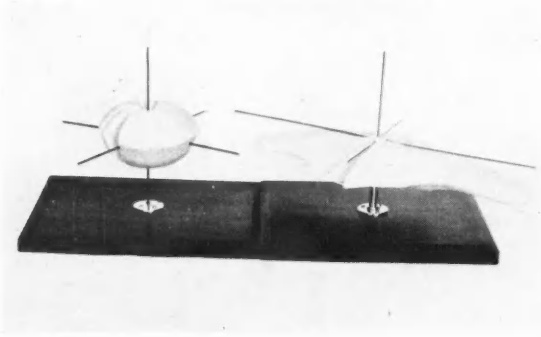


**Fig. 10.—Models of solid polar curves.**

*The only skill required, is that of the operator who must faithfully follow the vagaries of the track of the spot of light on the polar chart.*]

There is now a high probability that the accepted standard of luminous intensity will no longer, as heretofore, be a pentane lamp nor a Hefner lamp, or tungsten lamps calibrated in terms of these, nor even as defined by Act of Parliament, a "sperm candle weighing 8 to the pound," but that one sq. cm. of black body at the freezing point of platinum will be assigned the value of exactly 60 candles. Such a standard, though arbitrary, leaves the value of our present unit practically unaltered, and will always be reproducible. It has in fact been already reproduced to within an accuracy of approximately

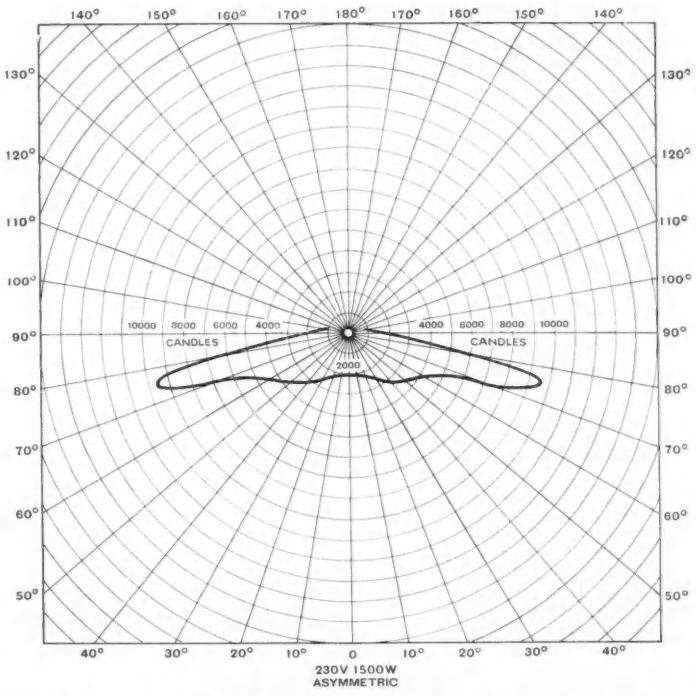



**Fig. 9.—Polar distribution curve of asymmetric refracting lighting fitting.**

0·2 per cent. at the Bureau of Standards, Washington and at the National Physical Laboratory, using averages of series of some 30 sets of determinations.

**(c) Total Flux.**

Before we pass from the measurement of intensity we ought to note the technique for obtaining a measure of the total flux of light from a source, or in other words its average intensity. The principle of the Ulbricht sphere is simple and attractive, but it is anything but simple to ensure that the magnitude of the unit of intensity of a standard in a single direction is accurately reproduced in the mean intensity in all directions of any given source. A diffusing, truly white surface, is required. It is easy to measure the mean intensity of a source in all directions and make a standard of it for putting in the Ulbricht sphere for calibrating it. But unless the light from the source ultimately to be measured has exactly the same hue as the light from the standard, errors may creep in. These errors can

be of the order of 1 to 2 per cent. with line sources, even when using the accepted white paints available for coating the sphere interiors.

If a photocell is used as a detector with a Ulbricht sphere it is sometimes convenient to place it in a subsidiary integrator (fig. 11). The window between the main and the subsidiary integrators is occupied by a shutter and appropriate colour filters which adjust the sensitivity and the spectral response of the photocell unit—and furthermore, as the photocell received integrated light, the arrangement avoids any inaccuracy, when using filters in this way, due to variations over the surface of the cell.

In fig. 12 is a photograph of an integrating photo-

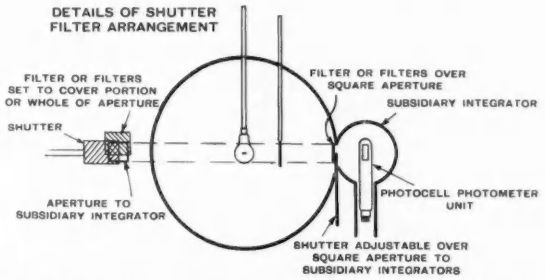

DETAILS OF SHUTTER FILTER ARRANGEMENT
FILTER OR FILTERS SET TO COVER PORTION OR WHOLE OF APERTURE
SHUTTER
APERTURE TO SUBSIDIARY INTEGRATOR
FILTER OR FILTERS OVER SQUARE APERTURE
SUBSIDIARY INTEGRATOR
PHOTOCELL PHOTOMETER UNIT
SHUTTER ADJUSTABLE OVER SQUARE APERTURE TO SUBSIDIARY INTEGRATORS

**Fig. 11.—Diagrammatic arrangement of integrators of photoelectric photometer.**

electric photometer[2] incorporating this principle and suitable for measuring tungsten filament and electric discharge lamps.

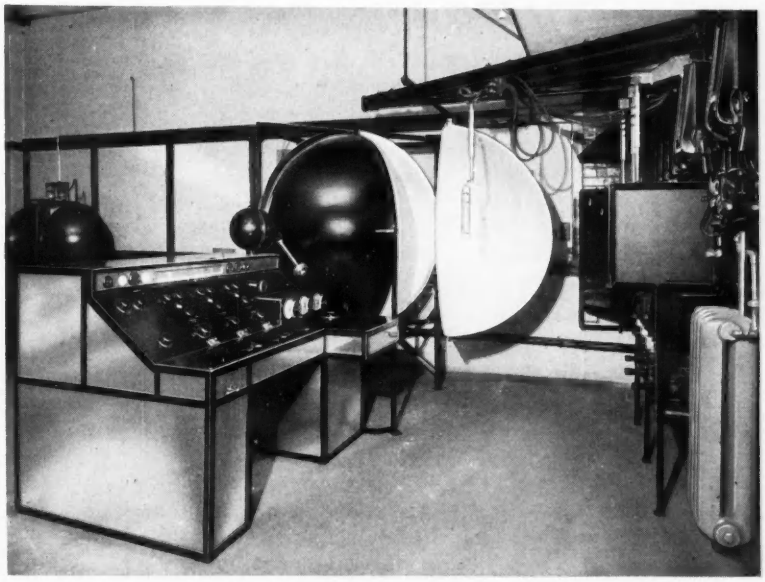


**Fig. 12.—Integrating photoelectric photometer for measuring tungsten filament and electric discharge lamps.**

GLARE.

Now these elaborate techniques we have been reviewing, and all the other refinements which on account of time I have not been able to touch upon, concern merely the appraisement of intensity. But the appraisement of light for seeing purposes depends but remotely on the intensity of sources of light. In fact I think we must agree that to the ordinary man in his seeing processes intensity is really but an abstract magnitude, except in one respect: the disturbances of vision owing to the presence of bright sources of light in the field of view is due primarily to the intensity of such sources. From this point of view, therefore, intensity *may* remain of importance as a practical magnitude. This phenomenon of glare has been investigated very carefully over the past few years.[3] Glare is encountered in one of its most exaggerated forms in our roads at night—where the two classes of glare are well exemplified. The first is disability glare illustrated by the motor headlight. Here vision of objects is to a large extent paralysed by the glaring effect of such lights. The second is discomfort glare illustrated by street lighting lamps which appear to be close to the objects it is desired to see. Such street lamps are sometimes bright enough in relation to their surroundings to cause a certain measure of disability glare; that is to say visibility is actually improved if the eyes are shaded from the direct light of the lamps. But Stiles' results show that as a rule these street lamps which appear in the field of view do not embarrass the eye in discriminating objects—but their deleterious effect is limited to causing a sense of discomfort. This probably depends on the intensity and brightness of the source, the nearness of its image on the retina to the fovea, and the darkness of the background of the general field of view in which such lights are located. I find there is a good deal of confusion of thought on this subject owing to a tendency to jump to the conclusion that when someone is conscious of discomfort glare, visibility is necessarily impaired. I have noticed, furthermore, a considerable difference in the sensitivity of individuals to discomfort glare.

Stiles has shown how the disability effect of glare for any set of conditions can be calculated from laboratory data, and has established much of the mechanism of disability glare; but in some problems practical conditions are so complex as to make the calculation uncertain and tedious, and in some

2. G.E.C. Journal, vol. 6, No. 4, Nov. 1935, p. 205.

3. "The Effect of Glare on the Brightness Difference Threshold." W. S. Stiles, D.S.I.R., Illum. Res. Tech. Paper No. 8.
"The Liminal Brightness Increment for White Light." W. S. Stiles and B. H. Crawford, Proc. Roy. Soc. B., No. 796, vol. 116, p. 116, pp. 55–102, Sept. 1934.

points the gap between laboratory and practical conditions has yet to be bridged. For example, when your field of view, instead of being a uniformly bright area as in laboratory work, is an area of very varying brightness and glare sources are scattered in it in positions which depend upon the layout of a considerable length of road, it is obvious that the collection of the essential data alone is a considerable task, and their interpretation is by no means either simple or certain. The very nature of the problem has made difficult the construction of a simple field instrument for measuring glare directly which is suitable for engineers to use, although one very ingenious field instrument was made and tried. We have also no way as yet of measuring discomfort glare, and in fact know little about it. One hopes that some work will soon be commenced on this side of the problem.

### IMPORTANCE OF "BRIGHTNESS AND CONTRASTS."

That derivative of intensity—illumination—is slightly more useful as a conception than intensity itself, and also as a practical magnitude. But it is not by illumination that one sees. Illumination is a useful magnitude to the engineer or the architect, who, like our tallow chandlers of old, chose to start the problem of seeing properly by providing sources of light. This has been certainly the easiest and most remunerative way to go about the business, but have its consequences been always favourable?

Suppose the Craft of Surgeons, represented in those days by the Worshipful Company of Barbers, had been powerful as well as enlightened physiologists. And suppose they had said:—

"This effort of the Tallow Chandlers to produce good seeing by providing candles is physiologically wrong, and incidentally, dangerous from the point of view of fire to our City. Man sees by contrast, and contrast alone, and contrast is produced by differences in brightness or in colour, between an object and its background, or between the parts of an object. It is true you may sometimes have to assist matters by providing a little artificial light, but study to make your contrasts the best possible for seeing. Your clothing, your articles of furniture, the walls of our houses, the colour of our materials for surfacing pathways, and all these factors which help to make things visible to the eye, are being left to chance. They must in future be attended to. We will find out how the various contrasts make things visible, attract attention, and please the aesthetic sense, and study colour and reflection factors of the paints and materials you use, and we will lay down standards. We will petition for a Charter to give us the powers to enforce such standards."

Is such an idea so far fetched as it may appear to some of us today? After all, it is not difficult to imagine a world in which artificial light sources were non-existent and in which man had to manage to see by the light of nature, whatever that might be at the time, and by the artificial enhancement of contrasts. The lamp maker as we know him today would of course not exist, and the world would be the poorer by the loss of a magnificent race of men. But would not their place be taken by an enormous industry supported by a century of painstaking research on the way in which we see—on paints, on colour combinations, and perhaps luminescent materials?

There are of course examples of this sort of approach to be found in some special cases. Thus, where we want to make something particularly

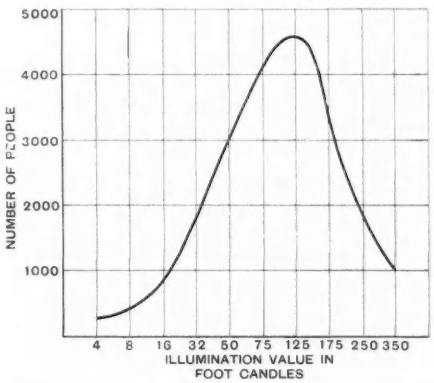



**Fig. 13.—Frequency distribution curve of Illumination values chosen by 21,179 people for reading a daily newspaper.**

visible, such as a buoy at sea or a Belisha beacon or a survey pole on land, we so colour them as to produce arresting and hard contrasts with their backgrounds. Cricket screens and the white boards placed behind some railway semaphore signals are other examples. And when we want something to be particularly invisible we copy the insects and birds (who knew all this long ago), and so colour it as to make its contrasts disappear and its outlines break up.

In any case a few centuries of postponement of the coming of artificial light sources, when the standards and magnitudes for appraising light could have been based on what one sees rather than the operation of lighting, might have done wonderful things in keeping our sense of values right—and it might have produced a world of human surroundings much brighter and better than the one we know today.

There are not a few who, today, are restive under the tyranny of the candle and the foot candle. Dr. Luckiesh of the U.S.A. has tried in his writings to urge the engineer to appreciate the essentials of the "science of seeing." There is for instance the school of street lighting engineers and physicists

who, because conditions for seeing are usually so difficult in street lighting, have had to study the essentials for good seeing under these exacting though specialized, conditions. This has compelled them to ignore to a large extent the traditional fundamentals of illuminating engineering, and to seek a more rational basis for their appraisement of lighting.

I do not want to appear altogether to condemn the use of illumination as a gauge for lighting, provided it is not employed as a criterion for situations where it is of little use. For instance, Mr. W. J. Jones has recently organized a most extensive and interesting survey of the illumination desired by ordinary people in the simple operation of reading a

**Fig. 14.—Portable brightness meter.**

newspaper. Here, illumination is clearly as effective a measure as brightness itself, because in such a test—with the black on white contrast of newsprint—the illumination is a sufficiently accurate gauge of the brightness. He obtains, for eyes adapted to a moderate brightness, a distribution curve for tests on 20,000 subjects (fig. 13), showing that people on the whole prefer brightness produced by an illumination of 100 foot candles on a surface which has a reflection coefficient of about 0·4. In other words, it has a brightness of 40 equivalent foot candles. This value of brightness is in a sense surprisingly high, for the figure to which we are accustomed in our homes or offices by artificial light is only of the order of 5 equivalent foot candles, and in our offices by daylight from 20 to 100 foot-candles.

### MEASUREMENT OF BRIGHTNESS—INSTRUMENTAL.

Where do we stand to-day in the technique of brightness measurement and in the expression of contrast for seeing?

I am afraid we are not very far when one remembers that colour contrasts as well as brightness contrasts enter into the problem.

The natural method of expressing brightness is of course in terms of intensity per unit area of the surface from which the light comes. Unless, however, the surface is very bright it is most inconvenient to measure directly "intensity per unit area." Instrumentally it is more convenient to compare the brightness of the surface in question with that of another known surface illuminated to such an extent that the two surfaces match each other in brightness. The illumination of the known surface is thus a measure of the unknown brightness. In this way we eliminate the necessity of measuring areas, and can express the result in terms of foot candles of illumination on a perfectly white surface. For simplicity rather than lucidity this latter unit of brightness has come to be termed the "equivalent footcandle" (or footlambert). I am not proud of this term, but no one has found one which is more suitable and it is constantly employed for every-day work and translated into candles per sq. ft. by dividing the equivalent foot candles, as measured, by $\pi$.

My only reason for dwelling on this is that nearly all the measuring devices used for brightness are similar in principle to illumination photometers. In fact, every visual photometer is a brightness photometer. When we wish to measure intensity, illumination or flux, we so arrange the instrument that a brightness is produced which is proportional to the quantity concerned. The surface, whose brightness is to be measured, is viewed in juxta-position to the white surface of known adjustable brightness.

Photometers intended for measuring illumination by viewing the brightness of an illuminated test surface can also be used to measure other bright-nesses. In general, photometers intended for measuring brightness must be specially designed with very small external fields. For the vision of objects largely depends on brightnesses which subtend very small angles, and the detail of brightness distribution is very important.

Although it is true that the eye is a very bad photometer from the point of view of its absolute response—as a relative brightness photometer it beats most of our instruments in reliability and sensitiveness.

There are one or two simple rough and ready portable types of brightness meter, figs. 14 and 15, whose accuracy may be put at $\pm$ 20 per cent. to 30 per cent.

Then there are optical brightness meters or telephotometers (fig. 16) which are of two main types:—

(*a*) The Maxwellian view type.

(*b*) The telescope type.

In the Maxwellian type a lens system focusses an image of distant brightness on the pupil of the eye. The eye then sees the lens flashed with the brightness of the distant object and the lens becomes one of the two comparison surfaces of a photometer system. This type gives a large and conventional photometer field and measures the average brightness over a

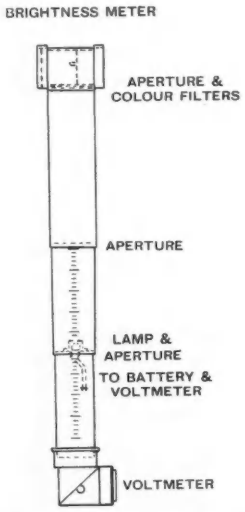



**Fig. 15.—Diagrammatic arrangement of a brightness meter.**

small angle. It is not, therefore, disturbed by a non-uniformity of object brightness. But for small external fields it becomes unwieldy and costly, and there is difficulty in defining the object viewed.

In the telescope type of brightness measurer a small photometer field is inserted into the field of view of a telescope and its brightness compared directly with that of the image of the distant object. The eye sees the telescope image with the photometer field superimposed.

This type permits of the measurement of very small objects and the exploration of the detail. It is small and cheap and there is no doubt as to the object being viewed. It has the disadvantage of being difficult to use at low levels of brightness, and with marked colour difference. A small telephotometer with a telescope multiplication of 10 can give a field as small as 3 minutes of arc. With a large telescope smaller fields could be used.

These photometers, if used for brightness survey, both involve some system of angular measure, in addition to the photometer proper, to determine the direction of view. Their accuracy under favourable conditions and when colour differences are not present may be of the order of $\pm$ 5 per cent.

### USE OF PHOTOGRAPHY IN BRIGHTNESS AND BRIGHTNESS CONTRAST MEASUREMENTS.

Recently, another way of appraising brightness has become more used for many new problems. In this the photographic plate is used in an intermediate stage between the eye and the brightness to be measured. The photographic emulsion has some characteristics very much like those of the eye, both in kind and in degree. The eye has, among others, two sensitivities which we may call the photometric and geometric; its sensitivity to *amount* of light and to the *direction* of light. The first is a very variable and uncertain sensitivity, and as we have seen, we only use it as a judge of equality, not in any absolute way. The second sensitivity, however, is very much more precise, and enables us to detect really extraordinarily fine detail in the objects we see.

The photographic plate is similar. It has a photometric sensitivity (by which it becomes blacker as it is exposed more) which is a rather variable quantity dependent upon many factors, and a geometric sensitivity or resolving power which is very much more precise. Once its vagaries are understood it is possible, by suitable technique, to use it in a great variety of ways for the appraisal of light. Almost always it is used as an intermediary between the object to be appraised and the eye.

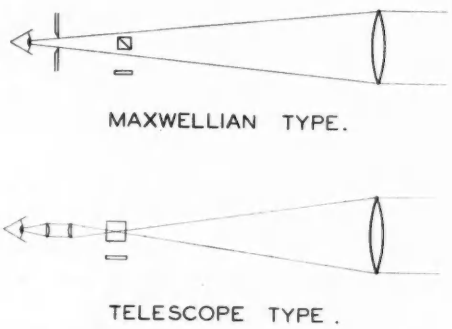



**Fig. 16.—Diagrams of optical arrangements of telephotometers.**

The photographic plate can record not only the amount of light, but its position or direction; it can record a whole distribution at once, and it retains a permanent record for future photometry if necessary, and has several other unique advantages For years, of course, it has been used in quantitative spectroscopy, and the way in which quantitative estimates of extremely minute amounts of material can be made through photography will be familiar to all physicists.

Generally, two methods of photographic photometry are possible. The first, uses the amount of blackening of a plate, to measure the light falling on it. If we use the plate to compare a series of unknown brightnesses with a series of known brightnesses—by comparing the densities of their images — fairly accurate results are possible.

The method has, for example, been developed and extensively used for studying brightness under street lighting conditions, for which it is particularly suitable. Fig. 17 shows such a photograph negative with its area of unknown brightness and with its known calibration brightness. We can plot out the brightness contours on a positive (fig. 18) of the negative, by means of the contouring densitometer (fig. 19). In this way the whole field of background brightness can be explored as well as, if necessary, that of objects seen against the background.

Sometimes the photographic emulsion is used in another way. There is a certain low exposure on the plate, below which nothing is recorded, and another high value above which no further increase of density occurs. If we use a very contrasty emulsion to take a photograph of a non-uniform brightness, and print on to very contrasty paper, we can sometimes make the photograph show one contour of brightness without any densitometer at all (fig. 20). On the right is one contour of a single bright area on a road surface from one light source. On the left is a contrasty print from such an emulsion —showing how definitely and faithfully such a contour can be obtained.

In the photograph (fig. 21) we have the distribution of brightness across the scanned line on the cathode ray tube of a television receiver at two different brightness levels.

Another method of photographic photometry has been used by astronomers for years for determining the magnitude of stars. This depends on the fact that, due to the nature of the light, imperfections in the object glass, unsteadiness of the air and photographic spreading, the size of the dot will vary with the brightness of the star according to the following empirical relationship.

$$M = m - k/d$$

where, d is the diameter of the star image,
m is the limiting magnitude of the photograph,
k is a constant determined from known magnitudes on the plate,
and M is the magnitude of the star as determined from the measured diameter d.

Fig. 17.—Photographic standard representation negative used in studying brightness under street lighting conditions.

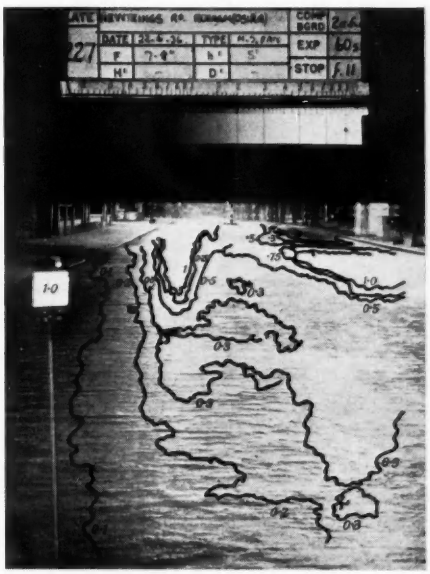


Fig. 18.—Positive of fig. 17 with brightness contours drawn in.

The constants are determined from a sequence of known magnitudes determined by various methods, one of these being a coarse wire diffraction grating which, when placed over the object glass produces images in the several orders, the ratio of the light in these being of calculable amount.

Still a further development, which is not a photometric method but is most useful in the appraisal of light, is the use of accurate photographic records—accurate in the sense that they convey, with sufficient precision for many purposes, the same impression to an observer as did the original scene. This has again been used as a technique for study of street lighting problems, and is a useful tool which can be used in parallel with the methods of photographic photometry to examine the characteristics of satisfactory and unsatisfactory distributions of brightness.

Thus, the two illustrations[4] (fig. 22) are of the same street. In one of them the artist has used all his craft to make the picture as flattering as possible. It gives a picture which has little resemblance to the truth, and merely appears to be a temptation to the salesman of street lighting fittings. In the other, the tone values have been determined from a knowledge of the values of brightness existing in the street and of the properties of the eye, so that the photograph conveys, under the conditions in which it is viewed, the most accurate impression possible of the original installation[5].

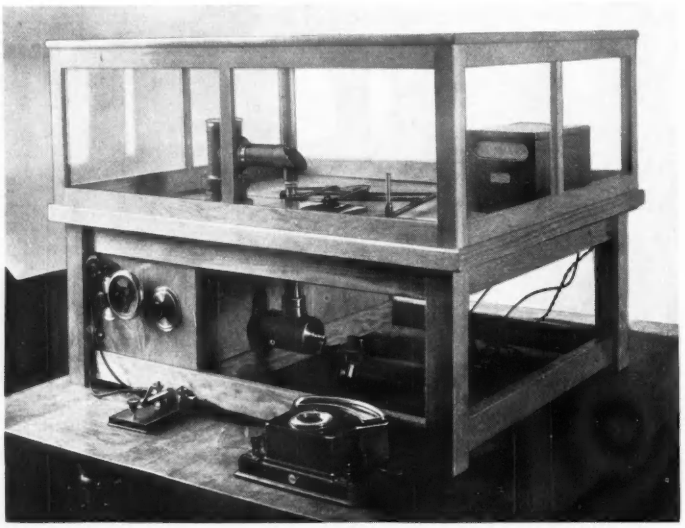


**Fig. 19.—Photoelectric contouring densitometer.**

Having now this quantitative way of securing correct tone values there would seem to be no excuse for many of the distorted photographs one is so often shown of lighting installations.

In spite of its great advantages for some purposes, the photographic method makes great demands on the skill and patience of the experimenter; it is complicated, expensive, and comparatively inaccurate; nevertheless it has rendered possible many investigations which can be done in no other way.

### PHOTOELECTRIC BRIGHTNESS MEASUREMENTS.

Photoelectric brightness photometry is generally very difficult. The cell is essentially a device for measuring illumination, and has a comparatively large light sensitive surface. In many brightness measurements the angle of subtense of the object is very small, so that the flux available is excessively small, and consequently, both in order to collect sufficient flux and in order to keep the external field small, very large optical components would be required.

For example, it has been possible to use this method for exploring the brightness distribution across a scanning line on cathode ray tubes used in television (fig. 23). In this case a fine slit is arranged to traverse a ten times enlarged image of the line, and a large aperture short focus (condenser) lens behind the slit condenses the light down on to the photocell cathode. This method is only made possible by means of the highly sensitive photoelectric photometer referred to earlier. Clearly this type of apparatus is too cumbersome for most types of brightness measurement, but is extremely useful for specialized applications.

### APPRAISEMENT OF CONTRASTS.

I have already indicated that the chief aim in measuring brightnesses is to facilitate the estimation of the contrasts by which we see objects. But there is the obvious objection in this, that whilst brightness contrasts may be measured, if there is a difference of colour the measurements have a very limited meaning. That is where our technique of measurement is so lamentably behind practical needs.

Little has been done for directly appraising contrasts even when there is no colour difference. All we do is to measure the brightnesses of the two contrasted surfaces. And even when we have done so there is no accepted method of expressing them in terms of their ability to cause the eye to see them and the brain to appreciate them. I know we have the historic measurements of Fechner's fraction which gives us the relative brightness difference

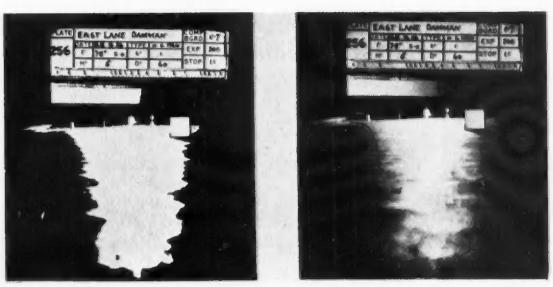


**Fig. 20 (Right) Contour of equal brightness obtained by Contouring densitometer.**
**(left) Contour of equal brightness indicated by high contrast photographic method.**

4. The lantern slides used to illustrate the lecture had regard to the properties of the projection lantern and the conditions of the theatre, the half tone illustrations in this paper are subject to limitations and do not faithfully reproduce the original prints.

5. R. G. Hopkinson, Trans. Illum. Eng. Soc. (London), vol. 1, No. 11, p. 19 Feb. 1936.
R. G. Hopkinson, Phot. Journ., vol. LXXVI, pp. 323-348, June 1936.

which we just *cannot* see in terms of the background brightness. But these results do not help us to assess practical contrasts which are greater than the threshold. We know the per cent. contrast which is just seeable—but it is seldom threshold values in which we are interested. The contrasts in the fields we look at are usually well above the threshold ; they must be if seeing is to be tolerable. An overcast day brings many contrasts nearer to the threshold, which on a sunny day stand out clearly. But a fuller attention to the subject by the pioneers might have evolved in some cases sunlight contrasts with overcast skies. The architects of course have done much down the centuries to apply the principles of contrast to building facades. They had to, for they had no aids to lighting externally.

And when we come to colour contrasts our ideas are limited to certain qualitative impressions. We say that yellow is a good contrasting colour, and we probably have opinions on other colours or shades. But a technique is needed for appraising such contrasts other than on the threshold.

Just recently the development of the television art has brought a new set of workers with some new techniques into the field of study of picture contrasts. This field has been so far mainly exploited by those interested in the photographic art. The work has been of high scientific merit and the nomenclature chiefly in terms of emulsion densities and photographic results.

But the television process gives an opportunity of controlling contrasts which has not hitherto been possible. For the details of the original picture as well as the details of the reproduced picture are both, at one stage, held in terms of electrical energy and can thus be manipulated—must in fact be manipulated—to give the most effective result. I cannot but believe that the continued effort, which television has started, to study the reproduction of scenes for the satisfaction of viewers, will carry a stage further the appreciation of the principles of good seeing of pictures of which the cinematograph industry has laid the foundation.

Quoting from a recent paper[6] on television images, it appears that the range of brightnesses in any picture used at present in television vary from about 15/1 to 120/1 compared with those used in cinemas of about 25/1 to 80/1. The television controls enable the contrast and brightness range to be varied at will as the picture is viewed—a technique hitherto not easily achieved. It is possible to give an indication of the effect of changing contrasts by superimposing two similar pictures, one very

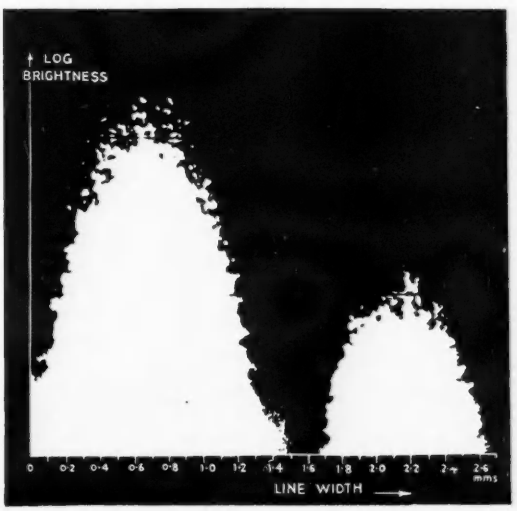



**Fig. 21.—Brightness distribution across single line on cathode ray television screen at two different brightness levels obtained by high contrast photographic method.**

6 L. C. Jesty and G. T. Winch, Trans. Illum. Eng. Soc. (London), p. 104, vol. II, No. 8, August 1937.

**Fig. 22.—Faithful (right) and flattering (left) representation of street lighting.**

"contrasty" and the other very "flat." The extent of the contribution of each picture to the combined picture is varied by a neutral absorbing wedge in front of each picture. Thus, within these limits, any degree of contrast is obtainable.

Furthermore, any value of average field brightness is secured by increasing or decreasing the intensity on the projector lamps.

It is of particular interest to note the effect of changing contrasts when the average brightness of the picture is low. When the contrasts are now made greater—although the average brightness is unchanged—we can note how much better is the seeing.

[*A "flat" picture at low value of brightness was shown on the screen, then the same picture with the same maximum brightness but with the contrasts increased.*]

## APPRAISEMENT OF COLOURED LIGHT.

In connection with the use of gaseous and vapour light sources for exterior lighting there is a good deal of discussion and experiment directed to show whether or not it is easier to see in the yellow light of sodium lamps than in that of the less monochromatic sources. Dr. Luckiesh has made a good effort to appraise sodium light under the categories of visual acuity, type reading test, speed of seeing, and accentuation or otherwise of contrasts. He comes to the conclusion that on balance sodium has no practical advantage over other sources of light. Others contend—mainly on the basis of visual acuity—that it has an advantage—forgetting, I think, that the seeing of fine detail is not usually the chief desideratum in exterior lighting.

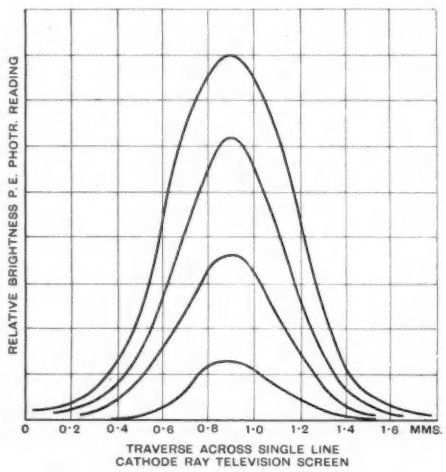



**Fig. 23.—Distribution of brightness across single line on cathode ray television screen obtained by photoelectric brightness photometer.**

We can perceive how much we are at sea in appraising the practical value of the different coloured light sources by lighting some not unusual colours alternately with sodium light and with a light covering the whole spectrum.

When this is done it can be seen how these contrasts which are clearly marked under normal light completely disappear or are reversed under sodium light.

Examining between 500 and 600 contrasts it is found that contrasts which are already marked tend on the whole to be more so under sodium light, whilst those which are normally less well marked tend to be still less so with sodium light.

I am calling attention in this way to the importance of colour contrasts with a view to showing how helpful it will be when principles for appraising them or techniques for studying them are better established.

There is such an immediate and pressing demand for simple techniques for measuring and specifying both the *colour* and the *colour rendering properties* of light sources, that we are likely to see a number of new proposals put forward in the near future.

In a desire to remain loyal to the internationally agreed tri-chromatic system, we should naturally turn to this system for a solution to our problem, but certain practical difficulties arise :—

Firstly, whilst the *colour* of the light can readily be specified on the I.C.I. tri-chromatic system, the types of visual colorimeter obtainable on which such measurements can be made are unsuitable for making rapid routine determinations, as they require skilled observers to operate them.

A much simpler and more rapid technique for indicating the colour of a light source directly on the tri-chromatic system has recently been evolved[7]. This consists of three rectifier type photocells covered with suitable colour filters and connected respectively to three galvanometers. By an appropriate optical system the galvanometers project line images so arranged that, with the galvanometer at zero, these line images form an equilateral triangle. The light which is to be analysed for colour, falling uniformly on the three photocell components causes deflections of the three galvanometers and movement of the three lines towards the centre of the triangle. By adjusting the total amount of light falling on the cells there is one position where the three lines must intersect at one point, which therefore represents directly the location of the colour of the light source under test within the trichromatic system of the triangle.

Thus, we have a ready means of measuring the *colour* but not the *colour rendering properties* of a light source. For we also want to know how the appearance of coloured articles and materials, etc., *i.e.*, the colour of the reflected light, will vary with different illuminants.

Secondly, the *colour rendering properties* of a light

7—G. T. Winch and E. H. Palmer, Trans., I.E.S., Oct., 1937.

source will depend on its spectral energy distribution, which may be different for light sources of the same colour, that is having the same tri-chromatic co-ordinates.

[*The different colour-rendering properties of light from a high pressure mercury lamp and from a tungsten filament lamp in front of which was a filter (daylight blue type glass), were then demonstrated.*]

In what manner shall we specify the *colour rendering properties* of a light source? If we consider electric discharge lamps the spectral energy distribution is dependent not only on the nature of the discharge, but on the type and proportions of luminescent materials used to modify the colour of the light. Apart from attempting to modify the spectral distribution in a manner which will give an approximation to daylight, there are many cases where a "warm" light is required. In these various cases we have to devise methods of appraising the *colour rendering properties* of the source.

Already many methods have been suggested, either based on measurements of relative energy or luminosity in various spectral bands, or on the visual judgment of the apparent colour of coloured materials, etc., when viewed under the various light sources. These methods have their uses, but are rather laborious, and liable to give misleading results.

Having, in the photoelectric colorimeter referred to earlier, a very quick method of measuring *colour*, why should we not make use of this to measure the *colour rendering properties*? For example, if we determine the *colour* of the light source, and also the *colour* of the light reflected from, or transmitted through, a suitably selected group of coloured materials, or filters, the relative position of these points in the colour triangle should enable not only the *colour* but the *colour rendering properties* resulting from the particular form of spectral distribution of the source to be determined. It will be obvious that in this case two sources which appear the same *colour* but are different in spectral distribution should be differentiated by the different values of the tri-chromatic co-ordinates of the reflected or transmitted light, from or through the coloured media.

The attraction of this method is that we use only the Internationally agreed tri-chromatic system, and can make our determinations at routine photometric speeds on one type of apparatus. Also, perhaps equally important, such results are closely related to what we see when looking at coloured articles or materials under different types of illuminant.

Meanwhile we are finding many practical cases where the new line spectra light sources are—on account apparently of their colour—giving better seeing in various industrial operations.

For instance, the new mercury light is being used to advantage in collieries on the picking belts to aid the distinction between coal and shale; also, in the Rand, on ore sorting belts where the presence of gold in ore can be better detected.

In galvanizing, the detection of flaws is made easier and in laundry work, scorches and iron-mould show up more readily.

In the pottery industry, cracks and blow holes are more easily detected in the early stages of firing—and this light has also proved more effective when inspecting for flaws in glass or for dirt in washed milk bottles.

The explanation of the real cause underlying the improved seeing in each of these cases might be instructive and may possibly be different for each one. I merely mention them to show that the subject is not an academic one.

Sodium lamps on account presumably of their monochromatic character are, of course, of use where very fine detail has to be detected.

### INTRINSIC BRIGHTNESS OF LIGHT SOURCES.

Under proper conditions of utilization of light for general lighting purposes it does not usually matter how bright the source of light itself is, for the art of diffusing light is well understood although perhaps not always practised. Therefore, for general lighting we are more concerned with the brightness of the glassware used in diffusing the light, than with the brightness of the source of light itself.

But when used for projection purposes the intrinsic brilliance of the source becomes vital; and it is not always realized how brilliant some of the new sources of light are, over what wide limits their brightness ranges, and what potentialities these have for projection.

Four or five years ago, you will remember, it was found that very great yields of light could be obtained by the passage of electricity through mercury vapour if the pressure of the vapour was increased. Some of the lamps which have resulted from this are well known now. Others are more experimental.

[*Enlarged images of three different types of mercury vapour lamps were thrown on the screen, one a well known lamp widely used for street lighting. It had a brilliancy of about* 160 *candles per sq. cm. compared with about* 1,000 *candles per sq. cm. of a tungsten lamp filament. The second lamp was smaller with a higher vapour pressure, and had a brightness of about* 1,000 *candles per sq. cm., i.e., some* 6 *times brighter. Another lamp had at the top a water-cooled envelope to dissipate the heat from the area round its very small and brilliant discharge column. The brightness was of the order of* 30,000 *candles per sq. cm. or* 30 *times brighter than the last.*]

The increasing brightness obtained with such lamps begins to make them comparable in brilliancy with high current density arcs used for searchlights and cinema projection.

We can press our ionized columns further still, the only limit being our ability to carry away the heat. If we do this the quartz lasts only a few minutes or seconds even when cooled with water.

[*The lecturer then showed a lamp with a brilliancy approaching* 150,000 *candles per sq. cm., a brilliance comparable with that of the sun.*]

The eye is an extraordinarily bad judge of brilliancy. We usually underestimate enormously a difference which may exist between the brightness of two sources, unless they differ in total candle power, when the brighter source may sometimes be mistaken for the less bright. This table of brightnesses of typical sources will indicate the range which is within prospect. Some of the higher brilliancy sources in this table have not as yet gone beyond the laboratory stage.

| Source of Light | Approx. Intrinsic Brightness Candles per sq. cm. |
|---|---|
| Carbon Filament .. .. .. .. .. | 20 |
| Tungsten Filament (Gasfilled Lamps) .. .. | 350 to 1,650 |
| Sodium Lamps .. .. .. .. .. | c. 10 |
| High Pressure Mercury 1 atmosphere, 230 volt | 160 |
| High Pressure Mercury 125 Watt. Pearl Bulb* .. | 50 |
| Brightness of column alone* .. .. .. | 1,000 |
| Mercury Water Cooled. 400 watts/cm., 300 Volts/cm.* .. .. | 30,000 |
| Mercury Water Cooled. 800 Watts/cm., 400 Volts/cm.* .. .. | 60,000 |
| Ordinary Carbon Arc .. .. .. .. | 13,000 to 17,000 |
| High Current Density Carbon Arc .. .. | 50,000 to 80,000 |

* Starting volts double running volts.

This review of some of the technique in use in the study of lighting and seeing has, I know, been disjointed and incomplete. In the compass of a short lecture this is inevitable. I tried to choose those aspects of the subject which seem to me to give the clearest picture of the art as it is today. If anyone troubles to criticise me I know I am vulnerable in my omissions. But I would ask such critics to bear in mind that I set out to demonstrate the state of an art mainly through the techniques which are in use for its study. As these techniques have become available during the past 30 years the art has changed and advanced greatly. Like so many other subjects, however, that of lighting and seeing has been and is held in check by the inevitable tendency of those who practise it to define it at any epoch in terms of the quantities which they can measure and the techniques they can understand. The illuminating engineer of yesterday was the candle power engineer of the day before. He is becoming the brightness engineer of today, but as soon as physics has provided suitable and understandable techniques for appraising contrasts he is surely fated tomorrow to become a contrast engineer. Whereas research can stretch out where it pleases, it is difficult for a practical art to advance faster than the established techniques for appraising its merits.

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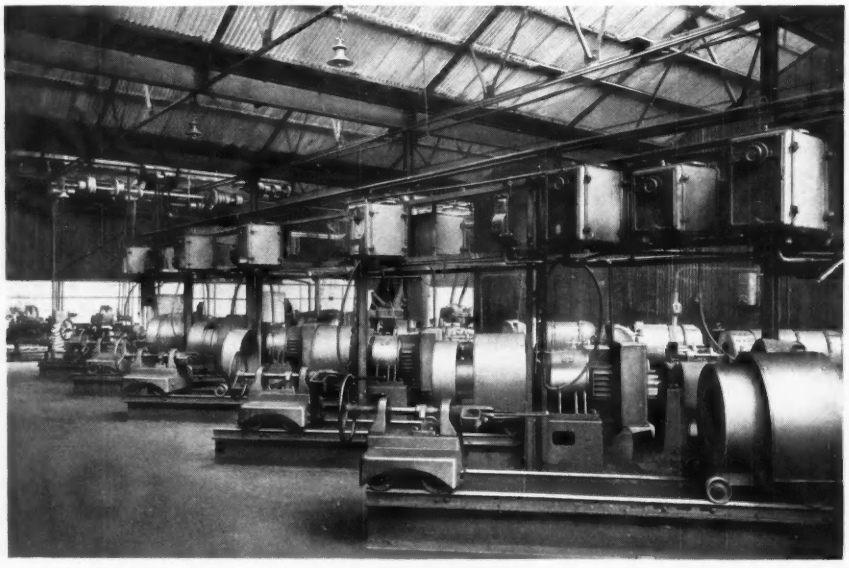
# Electrically Driven Centrifugal Casting Machines.



**Centrifugal casting machines at the works of the Sheepbridge Stokes Centrifugal Castings Co., Ltd., each driven by a 5 h.p., 230 volt, 800/2,000 r.p.m. D.C. motor.**

# The Design of Domestic Electric Cookers.

## PART I.

By O. W. HUMPHREYS, B.Sc.,
Research Laboratories of The General Electric Co., Ltd., Wembley, England.

*This paper was read before the Institution of Electrical Engineers on the 20th January, 1938.*

*The paper is devoted chiefly to those aspects of cooker design by which cooking performance is affected. Mechanical design is reviewed, but in much less detail, and mainly with the object of recording present practice.*

*The question of the indication of the "heating condition" of ovens is discussed, and the desirability is stressed of taking account of radiation as well as air temperature. Consideration is given to the problem of oven ventilation, particularly from the point of view of its effect on "steaming" at the vent. The advantages offered by thermostatic oven control are outlined and an attempt is made to forecast the changes, especially in connection with methods of heating and lagging to which it is likely to lead.*

*The history of the development of boiling-plates is briefly reviewed, and the relative advantages and disadvantages of the various methods of construction commonly employed in this country are discussed.*

### INTRODUCTION.

DURING the last quarter of a century, electric cooker development in this country has been proceeding along sound evolutionary lines, and until quite recently there has been but little tendency to break away from traditional practice. This does not mean that real progress has not been made. It rather implies that well-tried designs and constructional methods have been steadily improved as experience has shown the directions in which modifications could be introduced with advantage. In some other countries, changes of a more revolutionary and experimental nature have been introduced from time to time, but it is a question whether all these innovations have been really advantageous.

How much longer the present policy will be followed by British designers is a matter of conjecture, but it is the author's opinion that the next few years will see important changes in connection with both external appearance and oven design. That some manufacturers are already being influenced by a demand for cookers whose lines are more in harmony with present-day conceptions of artistic form is evidenced by some of the new models which have recently been introduced, and with the growing popularity of thermostatic oven control new problems arise in connection with oven heating, ventilation, and lagging, which may well result in a complete revision of present practice in these directions.

In this paper the author reviews present practice, and endeavours to indicate the probable course of future development. A brief historical survey is included where it is felt that this will facilitate an appreciation of the problems which have now to be faced. Except where the contrary is specifically indicated, all references are to the practices adopted, or developments anticipated in this country.

This review would be incomplete if no reference were made to the cookers working on the storage principle which have now been available for some years. These cookers were introduced on account of certain advantages which they offer to the supply undertaking from the load point of view, and can scarcely be discussed without consideration of supply conditions. Such a discussion falls outside the scope of the present paper, and as the cookers have already been described elsewhere[1] and the design problems involved are entirely different from those which arise in connection with the conventional type of cooker, it is not proposed to refer further to this interesting development.

### FACTORS AFFECTING DEVELOPMENT AND DESIGN.

Development and design are very markedly affected by many factors which have little, if any, effect on performance. Where, as is the case in this country, the majority of cookers are disposed of by simple hire or long-period hire-purchase, the supply authorities naturally demand a robust construction, which will ensure a long life and reduce the cost of maintenance to a minimum, and do not view with favour the incorporation of any new features which have not passed the most stringent tests. Frequent changes in external appearance are also deprecated owing to considerations of obsolescence.

In America, cookers are generally disposed of by direct sale or short-period hire-purchase. They are designed for a much shorter average life, and new features are continually added with the deliberate intention of rendering existing designs obsolete and encouraging their owners to obtain new, and more up-to-date, models.

The supply authorities demand the lowest capital cost compatible with the provision of adequate

1—G.E.C. Journal, 1932, vol. 3, p. 179, and 1935, vol. 6, p. 221.

facilities and satisfactory performance for their consumers, so that the hire or hire-purchase charges may be low and the number of cookers connected to their mains, and therefore their sales of electricity, may be as large as possible.

Building fashions must also be considered. Good appearance is essential when a cooker is to be installed in an attractively finished and fitted modern kitchen, and the small kitchens which are characteristic of present-day speculative building can frequently only accommodate cookers of very limited overall dimensions.

One of the great advantages of electricity as compared with the other sources of heat is its unobtrusiveness. The cook requires heat, ample in quantity and easily controlled, but the source of the heat does not interest her and the less conspicuous it can be made the better. Heating elements should preferably be arranged so that their presence may be ignored during cleaning operations, and every possible step should be taken to eliminate risk of accidental contact with live parts. With the high standard of reliability which has now been achieved, elements very seldom require replacement, and convenience and safety in daily use are more important than the very occasional saving of a few minutes.

High efficiency is desirable, but with the low rates at which electricity is now available, simplicity, convenience, and a high standard of performance may be considered of even greater importance.

Finally, interchangeability of parts between different cookers greatly facilitates the task of the maintenance staff of the supply authorities.

## GENERAL CONSTRUCTION FEATURES.

The cooker consists of a framework on which is mounted an oven, a warming cupboard, a hob, one or more boiling-plates and a griller or griller-boiler, together with the necessary wiring, switches, and fuses. The oven, boiling-plates, and griller, together with their associated equipment and accessories, will be considered in detail in later sections of the paper.

### Materials.

The framework generally consists of a base and front frame of cast iron with sides and back of sheet steel. The oven and warming-cupboard linings are constructed of sheet steel, and the hob is of cast iron. The oven interior is preferably welded so that steam is prevented from escaping into the lagging, and the joint between the oven lining and the front frame should be made in a steam-tight manner. Warming cupboards should be watertight, so that liquids spilled therein may not find their way into the lagging. The oven door consists of a cast iron door frame with inner and outer sheet steel panels. Sometimes the steel door panels are replaced by glass. The warming-cupboard door, when provided, is of the drop-down type and consists of a single casting or steel pressing, or may employ a cast-iron frame and a single sheet steel panel. The legs are usually of cast iron.

In America and on some parts of the Continent pressed-steel parts are extensively used in place of castings, but this practice, while it has not been entirely ignored, has not so far been at all widely adopted by British manufacturers. The advantages of pressed steel lie in the elimination of risk of breakage which is inevitably present with cast iron, its lighter weight, its smooth surface, which allows a very fine enamelled finish to be obtained, and the facilitation of assembly by mass production methods which results from the accuracy with which pressed parts can be produced.

Castings, on the other hand, are more rigid and less liable to warp under mechanical or thermal stresses ; they also offer the great advantage, which is of particular value during a period of rapid evolution, that they can be made from relatively inexpensive patterns which can be fairly readily modified, whereas steel pressings necessitate expensive tools which are not easily altered. The use of pressed steel introduces problems which do not arise with cast iron. In particular, special care in design is necessary to avoid distortion of such parts as hobs and front frames which are subjected to severe local heating and to steep temperature gradients. It is very important that a cooker should be designed to suit the materials of which it is to be constructed and that a design prepared for cast iron, for example, should not be used for pressed steel.

### Finish.

All structural metal parts, whether of cast iron or of sheet steel, are now almost invariably finished in vitreous enamel. This finish is attractive in appearance, very easily cleaned, very resistant to corrosion, and reasonably robust. A mottled-grey finish has been proved by experience to be the most durable, and therefore the best suited for use on cookers let out on simple hire. Some relief is usually given by the provision of a white panel in the oven door. Attractive colours are also available. If an acid comes into contact with the surface of ordinary vitreous enamel the glaze is quickly destroyed. Acid-resisting and acid-proof enamels can now be obtained and are commonly employed for hobs. Some manufacturers extend their use to all cast parts of the structure. The chief weakness of vitreous enamel is that once damaged it cannot be repaired, and to restore the original finish the affected part must be completely stripped and re-enamelled. This is a handicap to the manufacturer, and still more so to the supply authority that is faced with the necessity of reconditioning cookers returned from hire.

For parts such as oven interiors which are subjected to severe changes in temperature, vitreous enamel is not so satisfactory as it is for the external parts of the cooker, as "crazing" is liable to occur. Heat- and corrosion-resisting alloys which would not require any protective coating are available and would be more suitable, but their use would at present involve a substantial increase in cost.

#### Wiring, Switches and Fuses.

The majority of modern cookers have a wiring compartment on the right-hand side. The front frame casting extends over this compartment and carries the switches, of the reciprocating rotary type, in a vertical line. Local circuit fuses are generally provided in the circuits supplying the oven, the griller, and each boiling-plate, and access to them is gained either by removing a panel above or below the switches in the front frame or in the side plate, or by removing the whole of this plate. Terminals are provided for the reception of the supply and earth wires.

Electrical connections are usually made with bare or asbestos-covered copper wire. It is necessary to ensure that the covering used has adequate insulation resistance when damp, or alternatively to prevent contact between wires which may, with any of the possible switch positions, be of different polarity, or between the wires and the cooker body. In no circumstances should connecting wires be allowed to come into contact with slag-wool lagging. The temperature to which asbestos-covered leads can be safely subjected may be lower than that which is permissible for bare wire, owing to the presence in the covering of materials which accelerate the oxidation of copper.

#### Earthing.

It is most important that adequate steps be taken to ensure the proper earthing of all metal parts of the cooker which may accidentally become alive. Owing to the insulating properties of vitreous enamel, mechanical contact between the various parts is not sufficient. All parts of the cooker framework, exposed metal parts of fixed heating elements, and earth contacts associated with plug-in elements, should be bonded together and to the earth terminal by means of a copper wire or strip of suitable cross-sectional area. Bonding should also be provided where necessary between exposed metalwork and the earth pin on plug-in elements.

### OVENS.

#### Systems of Heating.

Any of the normal methods of heat transfer—radiation, conduction, and convection—may be employed for cooking purposes according to the results desired. The main difference lies in the degree of uniformity of the cooking between the outer surface and the centre of the charge. Whichever process is employed, the heat reaches the centre of the food by conduction from its surface. The degree of uniformity depends on the temperature gradient, which, in turn, is controlled by the conductivity of the food and the rate of absorption of heat at its surface. Generally speaking, radiation permits the greatest concentration of energy at the surface, and is therefore employed for such processes as toasting and grilling where a well-cooked exterior, and lightly-cooked interior, are required. Convection heating, with air at relatively low temperature, is preferred for such processes as the baking of cakes, where the highest possible degree of uniformity is desirable.

It is possible so to design an oven that heating is effected either by convection only, or by a combination of radiation and convection. Entirely convective heating is only obtained when the temperature of the surfaces bounding the cooking space is equal to that of the air in that space. This condition is very nearly complied with by the use of low-temperature elements, situated at the sides of the oven behind baffles which screen them from the cooking space and form, with the oven lining, ducts through which the oven air can circulate freely.

If free circulation is not permitted the air in the duct, and therefore in the baffle also will reach a temperature much in excess of that of the air in the cooking space, and food placed in the oven will be heated partly by radiation from the surface of the baffle. Elements are sometimes fitted beneath a perforated baffle situated in the bottom of the oven. In such a case considerable care must be exercised in determining the positions of the perforations if convection heating is the object.

The highest proportion of radiant heating is obtained from open-coil elements radiating directly to the cooking space. The only common example of this arrangement is the top element in top-and-bottom-heated ovens.

A system of almost entirely convective heating operating on lines similar to those described above is employed by one British manufacturer, but in general cookers intended for the home market employ heating systems intermediate between the two extremes. In many instances heating is by a combination of radiation and convection from the walls of the cooking space, which are themselves heated by elements clamped to or embedded in them, or by radiation from open-coil elements situated behind or below them. In other cases, the heating surface is that of some form of sheathed element which is situated inside the cooking space.

It is shown later that where an oven is to be thermostatically controlled convective heating offers very definite advantages, but with manual control

the choice of the heating system is largely a matter of personal taste. An experienced cook can produce excellent results with any system provided it is soundly applied, but a change from one system to another often involves changes in cooking methods which embarrass those who are less skilled, and earn for the newly adopted system a reputation for difficulty which is not deserved.

Ovens employing side heating only, or side-and-bottom heating, require a somewhat different cooking technique from those which are equipped with top and bottom elements. The chief difference lies in the method of control. With no top heat, control is by a single switch offering three alternative element connections, of which two only ("high" and "low") are at all commonly used. In top-and-bottom-heated ovens, on the other hand, the top and bottom elements are frequently controlled by separate 3-heat switches, and the top element is also used for grilling. Of the nine alternative element connections which are available, five are quite commonly used. The close control of the heating conditions in the oven which is thus made possible is of value to the expert cook, but to the average cook the selection of the best combination of switch positions presents some difficulty and is only learned as a result of considerable experience, or very detailed instructions.

Control is sometimes by means of a single switch offering three degrees of heat for oven cooking, in which case grilling facilities are provided elsewhere, or alternatively the element connections for the various switch positions may be as follows: (1) top element on full, for grilling and quick browning, (2) top and bottom elements on full, for preheating and commencing roasting, (3) half bottom element on, for all other purposes. Provided that the "low" loading is determined with care, this arrangement can give excellent results, and it makes the oven as simple to use as one with side, or side and bottom elements.

**Types of Elements.**

Oven elements may be classified as follows:—

(1) Those which are permanently wired and situated either (*a*) between the walls of the oven and the cooking space, or (*b*) outside the oven interior.

(2) Those which are arranged to plug-in in one of the following positions, and are withdrawable either from inside the cooking space or from the back of the cooker: (*a*) inside the cooking space (*b*) between the walls of the oven and the cooking space, (*c*) in cavities in the oven walls.

Elements in Class 1 (*a*) usually consist of heating coils mounted in grooved ceramic formers. They are associated with a lining to the cooking space which is removable for cleaning, and for access to the elements, in one or more pieces.

Arrangement 1 (*b*) offers an entirely unobstructed and therefore easily-cleaned, oven interior, with elements so completely hidden that the user need never be aware of their position; but this arrangement may involve some difficulty when element replacement becomes necessary. Wound mica elements are attractive for this purpose, but the wire temperature must be kept low to avoid dehydration of the mica, and very careful design, particularly in connection with the clamping system, is therefore necessary.

Where elements are so situated that cleaning can be facilitated by their removal, the plug-in arrangement has much to commend it. Very many types have been fitted from time to time. For use inside the cooking space [Class 2 (a)] some form of metal-sheathed element is essential, the coils being insulated from the sheath by ceramic formers, or by embedding them in refractory cement. The second subdivision of Class (2) includes open-coil elements mounted in frames equipped with plug connections, which give a performance identical with that of elements in Class 1 (*a*). Another type in this category consists of heating coils mounted in refractory tubes in a ventilated vitreous-enamelled housing. These elements are mounted behind vitreous-enamelled guards which are arranged to permit very free air circulation and so give the nearest approach to purely convective heating.

One example of Class 2 (*c*) consists of heating coils threaded through porcelain blocks which slide into channels in the oven lining. This type is removable from the back of the cooker, but only needs to be removed in the event of failure.

Plugs and sockets must be kept as cool as possible and must be made from metals which will withstand the temperature to which they are subjected without loss of contact pressure, and which will not "seize" if the elements are not withdrawn for long periods.

No difficulty should be experienced in so designing oven elements that the wire temperature is below 800°C. with the oven at its highest cooking temperature. Since at this temperature the life of the element should be practically indefinite, it is not worth while to make any appreciable sacrifice in other directions solely to ensure very quick element-replacement in the event of failure.

**Dimensions and Loadings.**

The enormous variety of sizes of ovens, and the wide variations in the densities of loading, are clearly shown in fig. 1, in which the relation between volume of cooking space and loading is plotted for the products of twelve manufacturers. The density of loading varies from 0·515 to 1·12 watts per cu. in. Similar diversity is found in oven dimensions, and while in the majority of cases depth is greater than height, and greater than, or equal to, width, there are quite a large number of exceptions.

**Ventilation.**

With electrically-heated ovens it is not necessary to maintain a circulation of air through the oven, but some provision for the removal of the large quantity of water which is evaporated during most baking operations is required. Usually a single opening is provided either at the top or at the bottom of the oven door, at the back of the oven, or between a part of the door frame and the front frame of the cooker. Adjustable dampers are sometimes fitted to enable the area of the vent to be controlled.

Some manufacturers provide adjustable vents in both the top and the bottom of the oven door, thus permitting through ventilation, and in one instance permanent openings are provided in the bottom of the oven beneath the heating elements, and in the top of the oven.

When a single vent is provided and the oven door fits really well, so that there is no possibility of air entering the oven through the door joint, evaporated water passes through the vent in the form of steam. If immediately it leaves the vent it comes into contact with cold air, it condenses into a cloud of visible water vapour. If the air is warmer the steam has time to diffuse before it condenses, or is absorbed by the air, and its presence is not noticeable.

When through ventilation is permitted, either intentionally by the provision of two vents, or unintentionally because the fit of the door is not perfect, the amount of air passing through the oven may be sufficient to absorb the water which is evaporated. Some condensation may occur as the air cools, but the velocity of the water-laden air as it leaves the vent is much higher than that of the steam in the case previously considered, and the opportunity for diffusion and partial re-absorption by the general air of the room is therefore much greater.

The action of through ventilation in reducing condensation around the vent can often be demonstrated by selecting an oven which does not normally exhibit this effect, and packing the joint between the door frame and the front frame of the cooker with paper. By this means accidental ventilation is eliminated, and condensation will frequently commence.

"Steaming" at the vent is frequently regarded as indicating a defect in the cooker. Actually, as has been shown, it may merely arise through the use of a particularly well-fitting door, and the presence or absence of this phenomenon has no bearing whatsoever on the quality of the cooking. Vents are provided to enable steam to escape from the oven. Whether this steam condenses just outside the vent, or on the walls of the kitchen, or is absorbed by the air in the kitchen, is of but little importance.

**Internal Fittings.**

Ovens are supplied complete with wire shelves and shelf-runners. The latter may consist of special frame-works which clip on to the side walls of the oven, or they may be formed integrally with the walls. In either case the combination of shelf or runner should be such that the shelf can be partially withdrawn without tilting. Pressing the runners into the oven walls or element guards reduces the number of removable parts and facilitates cleaning.

**Lagging.**

*Materials.*—A perfect oven-lagging material would possess the following properties: (1) Low thermal conductivity. (2) Maintenance of condition and properties when repeatedly heated to the maximum temperature reached during cooking, or when the oven is accidentally over-heated. (3) Ease of application. (4) Freedom from corrosive effect on the materials with which it comes in contact. (5) Freedom from "settling" when subjected to vibration. (6) Low cost.

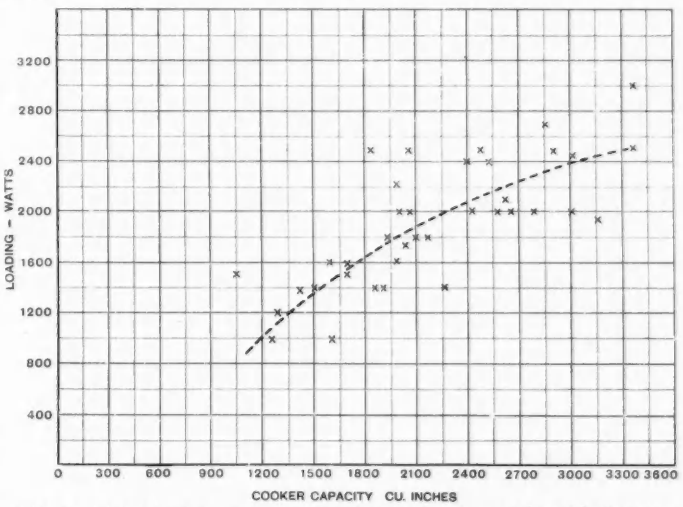



**Fig. 1.—Relation between oven loading and volume of cooking space.**

Slag wool, which is at present very widely used, fulfils many of the requirements. Its thermal conductivity is very low and it can be easily and quickly packed into a space of any shape; it has good heat-resisting properties, and its cost is very low. On the other hand, it is fairly strongly chemically reactive, and it is essential that all metal surfaces with which it comes in contact should be adequately protected, as, for example, by vitreous-enamelling. If not very tightly packed, slag wool tends to disintegrate and "settle" under vibration, and it is not a very pleasant material to handle. Rock wool, which is generally similar to slag wool, but more free from corrosive constituents, is commonly used in America and to some extent in this country.

Glass silk possesses all the desirable features of slag wool and is at the same time non-corrosive, much more pleasant to handle, and, on account of the long threads in which it is produced, less liable to settle. Unfortunately its use in a highly competitive market has so far been excluded by its relatively high cost.

Insulating materials made up into slab form of such shapes that the complete lagging of the oven

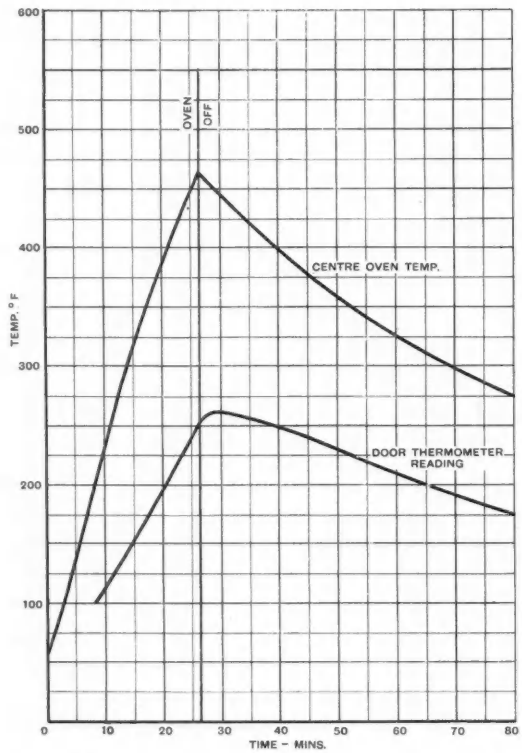



**Fig. 2.—Relation between centre oven temperature and door-thermometer bulb temperature.**

can be achieved by the use of 6 slabs, reduce the labour involved in applying the lagging to a minimum, ensure uniformity of insulation, and completely eliminate settling. The oven must be specially designed, however, to enable slabs of simple geometric shape to be used.

A further alternative is aluminium foil arranged round the oven interior in a number of layers separated by air spaces of about 1 cm. thickness. In this way a lagging effect at least equal to that given by a similar thickness of the best of the more conventional types of lagging material is obtained. The cost of the foil is very low, but this may be offset by the cost of spacers and of labour. Complete freedom from settling or corrosion troubles is assured. On account of the very low heat capacity of the foil, pre-heating times are reduced and, as is shown in another part of this paper, thermostatic control is simplified. Lagging spaces must be of simple shape. Various methods of spacing the foil, some of which are covered by patents, have been proposed.

*Thickness.*—As the thickness of the lagging on an oven is increased the heat-loss to the atmosphere from the outer walls of the cooker is reduced, and the loss by absorption in the lagging material becomes greater. From the point of view of economy in energy consumption, it has been shown experimentally that lagging thicknesses considerably greater than those now commonly used would be well justified. For example, the energy consumption during the cooking of a series of meals in an oven lagged with 3ins. of slag wool was found to be approximately 25 per cent. lower than in an identical oven with only 1in. of lagging.

Running cost is not the only factor to be considered however; account must also be taken of capital costs, and the limitations on overall dimensions imposed by considerations of space, and in view of the low prices at which electricity is now generally available these latter considerations are undoubtedly of the greater importance.

**Temperature**

*Indication.* — The quantity which determines whether an oven is in suitable condition for the carrying-out of any particular cooking operation is the rate at which heat would be transferred to the surface of a charge placed therein. For brevity this quantity will be referred to as the "heating condition" of the oven.

Before the days of electric cooking the cook usually determined heating condition by inserting her hand into the oven, or by other primitive, but not therefore necessarily unsatisfactory, methods. With the introduction of electric heating, precise control of heating condition became possible and the desire for some indication of that condition followed naturally. The method adopted was to fit, usually to the door of the oven, a thermometer calibrated in terms of oven temperature. Owing to the necessity of protecting the thermometer from damage, and of avoiding encroachment on the cooking space, the bulb of the thermometer (or the bimetal coil, if a heat indicator of that type be used) is usually recessed into a cavity formed in the door lagging. The temperature in this cavity is inevitably lower than that of the main body of air in the oven, but to an extent which depends on a variety of circumstances and varies between quite wide limits.

Figs. 2 and 3 show the relation between true centre oven temperature and the thermometer indication for one modern cooker which was fitted, for the purposes of the experiment, with a thermometer calibrated to read true bulb temperature.

Fig. 2 records the results obtained when the heating elements were switched off immediately the oven temperature reached 450° F. (232·2° C.), while fig. 3 shows the effect of switching to "low" for a period of 1 hour before switching off. It is not suggested that the discrepancy is always as great as indicated in the figures, but, in a greater or lesser degree, it is inevitably present.

It is clear from the figures that any attempt at a division of errors is out of the question, as those remaining would be so great as to render the indication of the thermometer practically valueless at all times.

As an accurate knowledge of temperature is of the greatest importance at the time that the food is inserted in the oven, it is customary so to calibrate the thermometer that it indicates true oven temperature during initial heating from cold. Thereafter the thermometer readings bear an indeterminate relation to oven temperature and are of little real value, but this is only a serious inconvenience when it is desired to carry out in succession two cooking operations requiring substantially different temperatures.

Careful attention must be given to the mounting of the thermometer in the oven door, as seriously inaccurate readings will be obtained unless an air-tight seal is provided between the thermometer stem and the oven interior, to prevent the passage of cold air from the outside atmosphere over the bulb.

It is essential that thermometers should be able to withstand, without mechanical damage or change of calibration, the highest temperature that the oven may reach if it is inadvertently left in circuit at maximum loading. With the bimetallic type of indicator this necessitates special care in the choice of the bimetallic combination, since some materials which would be entirely satisfactory if heated through the range of temperature normally used in cooking, would become over-stressed if heated to the maximum temperature obtainable with full oven loading.

*Significance.*—The rate at which heat is transferred to a charge in an oven depends in part on the air temperature, but in part also on the temperature of the surrounding surfaces from which it receives heat by radiation. It is therefore impossible to define heating condition completely in terms of air temperature, and this difficulty is reflected in the widely differing temperatures which are recommended by various cooker manufacturers for the same operation. If one goes outside the field of electric cooking and includes ovens heated by gas or solid fuels, the variations become still more marked.

In any individual cooker a knowledge of air temperature only enables a previously-obtained heating condition to be repeated, but with every change in the proportions of radiant and convective heating the relationship between air temperature and heating conditions is altered, and revised cooking instructions become necessary. So long as this state of affairs exists, the preparation of cookery instructions which will be applicable to all types of cooker is out of the question. The difficulty could be overcome by calibrating the heat indicator in terms of heating condition instead of oven temperature, with a scale of "heat numbers" in place of degrees Fahrenheit. This is the common practice with thermostatically-controlled gas cookers, and has been adopted by some manufacturers of thermostatically-controlled electric cookers, but as there is at present no agreed standard scale of heat numbers definitely correlated to heating condition (the gas industry uses at least 6 different scales) the limitation of the present arrangement is perpetuated. It is

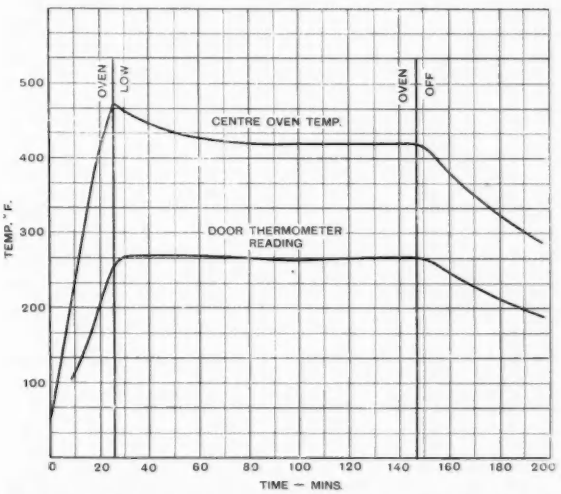



**Fig. 3.—Relation between centre oven temperature and door-thermometer bulb temperature.**

suggested that the development of a standard scale would be of great value. It would facilitate the change from one type of cooker to another, and would also greatly increase the number of recipes on which users of any particular cooker could draw. Associated with it there would have to be a standard method of determining heating condition. A. H. Barker,[2] during the course of an experimental investigation of solid-fuel-heated cooking ranges, developed a calorimetric method of determining the rate of heat transmission to a charge in the oven, and carried out a preliminary research concerning the rate of transmission required for various cooking operations. Much experimental work would undoubtedly be necessary to determine the applicability of any methods which might be proposed to all types of cooker under all conditions. In the meantime it might be possible to fix a scale in terms of various cooking processes—No. 2, for example, correspond-

2—Special Report No. 4 of the Fuel Research Board.

ing to the heating condition required to bake milk puddings, and No. 7 to that required for roasting beef, etc. This procedure has already been applied by one manufacturer of thermostatically-controlled electric cookers. The correct calibration for each type of cooker has at present to be determined by actual cooking tests. This method may be a little cumbersome, but it at least has the merit of being certain.

**Measurement.**

A word concerning the measurement of oven air temperature for experimental purposes may not be out of place. Owing to the effect of radiation special precautions have to be taken to ensure that the reading given by a pyrometer is not higher than that of the air. Some years ago the author carried out a series of measurements using four types of pyrometer, as follows: (*a*) A thermocouple attached to two very thin copper discs of 2ins. diameter welded together at right angles. This arrangement was on the lines previously suggested by E. Griffiths[3], but with his single disc replaced by the two discs to eliminate the effect of the orientation of the disc with respect to the elements. (*b*) A thermocouple consisting of 0·8-mm. diameter copper and eureka wires with the junction between them welded. (*c*) As (*b*), but employing 0·1 mm. diameter wires and with the welded joint as small as possible. (*d*) A resistance thermometer made from 0·03-mm. diameter platinum-iron wire wound on vacuum-lamp frame.

Comparative readings were obtained with all these instruments in an oven with top and bottom elements, the top one being, as usual, unshielded. The readings obtained with the four pyrometers, in the above order were as follows: 469° F. (242·8° C.), 417° F. (213·9° C.), 405° F. (207·2° C.), and 384° F. (195·6° C.). As all the pyrometers had a very low heat-capacity the question of lag of the pyrometer temperature behind the air temperature does not arise, and the lowest readings must be the most accurate. Measurements were also made in a side-heated oven with protected elements using pyrometers (*a*) and (*c*) only. In this case the radiant heating was greatly reduced and the difference between the readings was only 14 deg. F. (7·8 deg. C.) From this it is concluded that in the absence of completely-exposed elements the readings of a fine-wire couple will be sufficiently accurate, but that a resistance thermometer, such as is described above, should be used when such elements are fitted.

**Thermostatic Control.**

*Effect on Cooking Performance.*—Thermostatic oven control received some consideration in the very early days of electric cooking, and some 2,000 thermostatically-controlled electric cookers were made by one British manufacturer. A mercury thermometer, with sealed-in contacts, served as the thermostat, the circuit being controlled through the medium of a relay. Generally speaking, however, it must be admitted that it is only during the last few years that thermostatic oven control has received serious attention in this country. In America it has been well established for many years. The public has become so used to thermostatic control, through its very successful exploitation in connection with gas cookers, that there is very little doubt that the demand for it on electric cookers will grow rapidly now that it has become available. It may be argued, apparently with a fair amount of justification, that the manual control of electric ovens is so simple that the thermostat cannot possibly have much to offer, but experience shows this view to be mistaken.

The chief advantages, especially when cooking has to be fitted in with other household duties, are undoubtedly the removal of the risk of overheating during the pre-heating period and of all need for attention while cooking is in progress. In addition, cooking is simplified and better results are likely to be obtained. The reasons for this are as follows: (1) By adhering to predetermined thermostat settings uniformity of results on different days is assured. (2) With certain long-period cooking operations, especially those requiring a low temperature, it is sometimes difficult with manual control to maintain the desired temperature with accuracy throughout the whole period. Thermostatic control eliminates this difficulty. (3) Thermostatic control removes the difficulty already referred to in connection with oven thermometers so far as the carrying-out in succession of cooking operations requiring different temperatures is concerned.

An important difference between manual and thermostatic control is that whereas with the former cooking is usually carried out with a falling temperature, with the latter the temperature is maintained at a steady value throughout the whole operation. As a result of this, the oven temperatures required with thermostatic control are lower than those which are recommended for the *beginning* of cooking with manual control.

*Technical Considerations Affecting Design of Thermostat.*—Great care must be exercised in choosing a thermostat to ensure that it is really suitable for the particular cooker to which it is to be fitted, since different systems of oven heating, and methods of applying thermostatic control, may call for widely differing characteristics in the control instrument. The usual method of application is for the whole of the preheating load to be under thermostatic control throughout the entire cooking period.

3—Journal I.E.E., 1921, vol. 59, p. 367.

Occasionally this load is reduced, either automatically when the thermostat first cuts out, or by the operation of a switch when the food is put into the oven; and in some instances a small proportion of the total load is left in circuit continuously, the balance being controlled by the thermostat.

It is of the first importance that, once the thermostat has started to operate, cooking results should be independent of the time at which the food is inserted in the oven. To achieve this, the amount of heat absorbed by the charge must be the same whether the charge is inserted immediately after the first cut-out of the thermostat or at any later time. At first sight it might appear that this condition would be met provided the change in oven temperature between opening and closing of the thermostat was small. With an oven heated entirely by convection, and the rate of transfer therefore depending only on air temperature, this would be true, for a small change in temperature would represent a very small alteration in heating condition. If radiation plays any important part, however, it is no longer the case, for since the radiating surfaces are usually associated with bodies of relatively low heat capacity, they change in temperature very rapidly when the thermostat operates, and in consequence the heat-transfer by radiation varies between wide limits in a very short space of time. Consequently, the rate of heat transfer is much greater during the "on" period than it is during the "off" period, and the only way to ensure the same total heat-transfer during a given time is to employ a thermostat which operates with a very short time cycle. A further objection to a long time cycle is that it may lead to over-heating, and consequent burning, of the parts of the charge in closest proximity to the radiating surfaces. With the general run of present-day cookers this cycle should not much exceed 5 mins., and a shorter period is frequently advantageous. Even with so short a cycle the cooking of such items as small cakes will not occupy a sufficient number of cycles for the results to be independent of the time of insertion, and more uniform results are frequently obtained by slightly increasing the initial temperature and switching off when the charge is placed in the oven.

With well-lagged ovens, such as are commonly made in this country, the rate of cooling is so low that a short time cycle involves very close control of air temperature, and a very sensitive thermostat (*i.e.*, one with a very small temperature "differential") is therefore required. A small differential usually implies low contact-pressure, and a short time cycle involves a very large number of operations. With a time cycle of 4 mins., for example, and the oven in use, in an extreme case, for 2 hours a day, the number of operations would be about 11,000 per annum, or anything from 50,000 to 100,000 during the life of the cooker. Very careful design and testing is necessary to ensure that the instrument will not only function satisfactorily for the required number of times as a switch, but that it will do so without serious change in operating temperature or differential.

The nature of the problem will be appreciated when it is realized that with a thermostat of the type which is actuated by the differential expansion of a rod and tube, a change in temperature of 10 deg. F. (5·6 deg. C.) only produces a differential expansion of about 0·001 in. Conversely a change of 0·001 in. in the relative lengths of the two members results in a change of about 10 deg. F. in operating temperature. Great care is therefore called for, both in design and in choice of materials, to eliminate alterations in dimensions such as may occur in metals owing to annealing or to creep under mechanical load, and in insulating materials owing to shrinkage under the influence of heat.

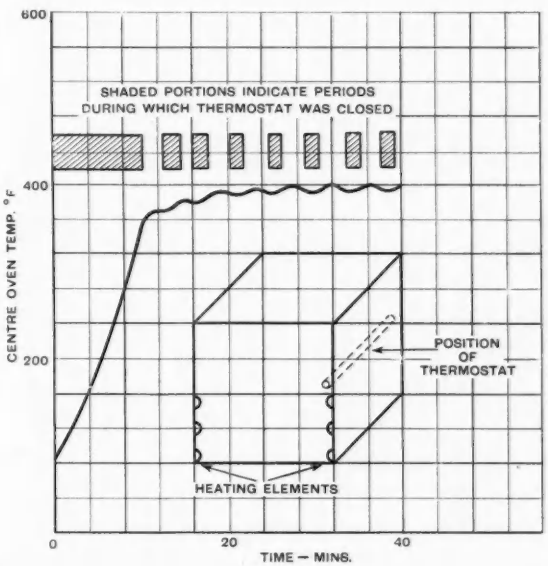



**Fig. 4.—Effect of thermostat position on control of centre oven temperature : thermostat too near the heating elements.**

Some types of thermostat employ bearings which are exposed inside the oven, and in such cases the effect of carbonized fats, etc., on the free working of the instrument requires consideration.

*Effect of Thermostat Position on Performance.*—The performance of a thermostat is very largely influenced by its position in the oven. The best position depends on the type and disposition of the heating elements, and the system of ventilation employed, and must be determined experimentally. Fig. 4 shows the effect of placing the thermostat

too close to the elements. The temperature of the air surrounding the thermostat rises more quickly than that of the air in the centre of the oven. Consequently the first cut-out occurs before the final temperature has been reached in the centre of the oven, and several further cycles have to be completed before steady conditions are established. The preheating period is thereby increased. As shown in fig. 5, the operation is very substantially improved by moving the thermostat farther from the elements, the temperature at first cut-out then being actually above the steady-state value by about 12 deg. F. (6·7 deg. C.). A small overshoot such as this has no harmful effect since the temperature falls immediately the oven door is opened to insert the food. A further point brought out by these two figures is the reduction in differential obtained by placing the thermostat near the elements, the values obtained in the two cases being 10 deg. F. and 18 deg. F. (5·6 deg. C. and 10 deg. C.) respectively. From this point of view performance is better in the first position once steady conditions have been established, but in view of the effect on preheating time the arrangement is not admissible.

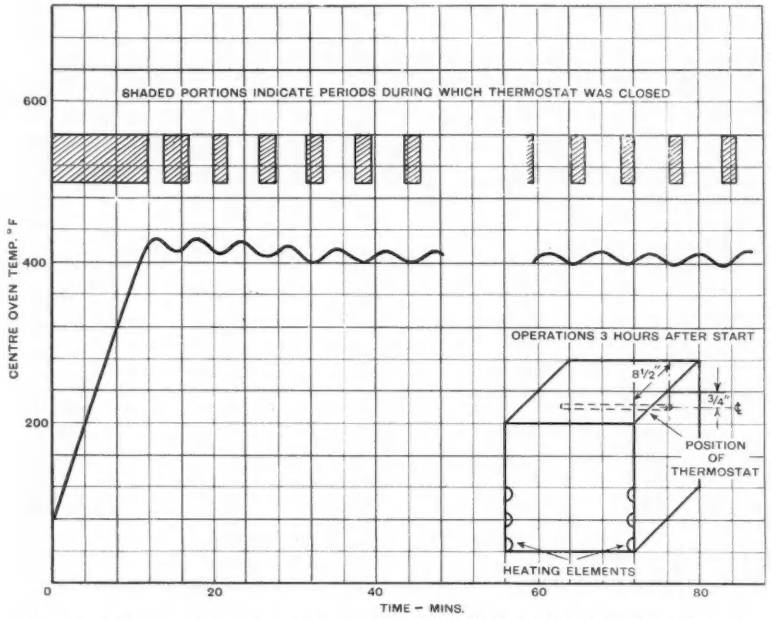



**Fig. 5.—Effect of thermostat position on control of centre oven temperature : as fig. 4, but with thermostat correctly placed.**

Precisely the reverse effect, obtained by placing the thermostat in a corner of the oven, very near the walls, where air circulation is restricted and the temperature rises more slowly than at the centre of the oven, is shown in fig. 6. In this case the centre oven temperature at the first cut-out is some 60 deg. F. (33·3 deg. C.) above the steady-state value. The broken line shows the air temperature near the thermostat, and it will be seen that the temperature in this region continues to rise for

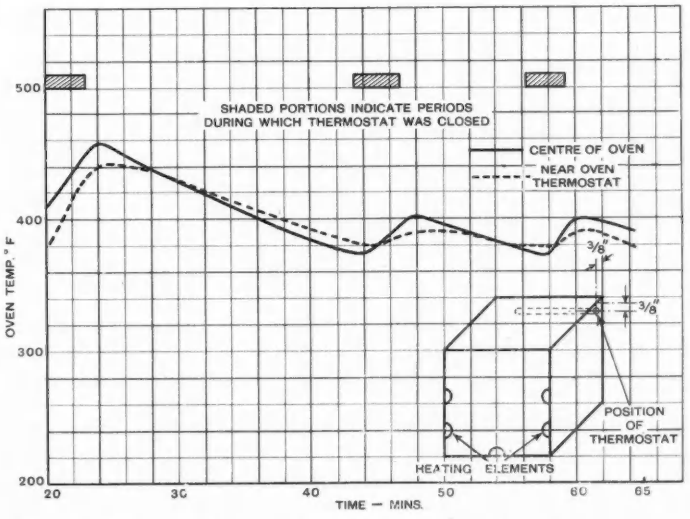



**Fig. 6.—Effect of thermostat position on control of centre oven temperature : thermostat situated in region where free air circulation does not occur.**

more than a minute after that at the centre of the oven starts falling. It will also be seen that the differential at the centre of the oven is 26 deg. F. (14·4 deg. C.) as compared with 12 deg. F. in the neighbourhood of the thermostat. By moving the thermostat farther from the back wall, into a region of freer air circulation, the greatly improved, and entirely satisfactory, performance shown in fig. 7 is obtained.

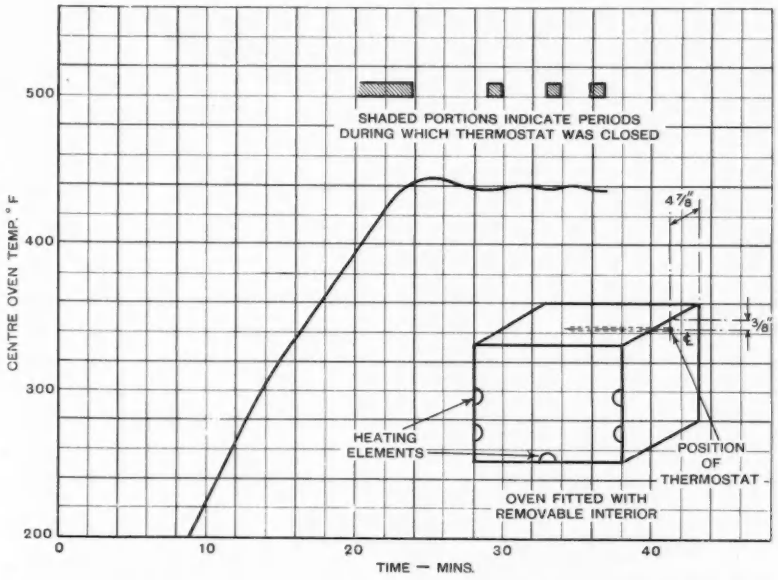



**Fig. 7.—Effect of thermostat position on control of centre oven temperature: as fig. 6, but with thermostat correctly placed.**

*Effect of Oven Design on Performance.*—It has already been mentioned that in order to obtain a sufficiently short time cycle with present-day British cookers, very close control of air temperature is necessary. Provided the length of the cycle was not increased, a much wider variation in temperature would, however, in no way detract from cooking performance. As such a change would simplify the design of the thermostat it is worth considering whether there are any means by which it could be brought about. Two possibilities suggest themselves, the first being to reduce to a minimum the heat capacity of those parts of the oven which undergo temperature-change, and the second to reduce the amount of lagging.

The latter expedient is the less desirable since it involves an increase in energy consumption, and therefore in the cost of cooking, whilst reducing heat capacity has no such effect. In the majority of ovens the parts whose heat capacities are most susceptible to reduction are the heating elements and the lagging material. The heat capacity of the latter could be almost entirely eliminated by the use of aluminium foil.

An alternative line of approach is to decrease the amount of radiant heating. The length of the time cycle then becomes of less importance, and if a system of entirely convective heating could be developed the time cycle should be of no importance whatsoever since the heating condition would depend only on oven air temperature. A slow rate of change might then be an advantage owing to the reduction in the effect of lag between the thermostat and air temperatures.

[*To be continued*].

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